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(54) Engine exhaust purification device

(57) A controller computes an oxygen storage amount of a catalyst based on the characteristics of an exhaust flowing into the catalyst, and controls the air-fuel ratio of an engine so that the oxygen storage amount of the catalyst is a target value. When it is determined that the engine starts from the warmed-up state when the engine starts, the air-fuel ratio of the engine is controlled to rich until the exhaust flowing out of the catalyst becomes rich. In this way, all the oxygen stored by the catalyst is first released, the NOx purification performance of the catalyst is maintained, and the NOx release amount immediately after engine startup is suppressed.

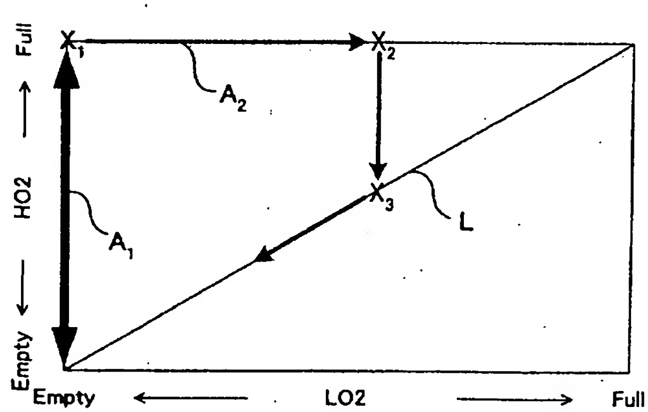

FIG.2

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to an engine exhaust purification device provided with a catalyst.

BACKGROUND OF THE INVENTION

[0002] JP-A-H9-228873 published by the Japanese Patent Office in 1997 discloses a technique wherein an oxygen amount stored in a three-way catalyst (hereafter, "oxygen storage amount") is estimated based on an engine intake air amount and an air fuel ratio of an exhaust flowing into the catalyst, and engine air-fuel ratio control is performed so that the oxygen storage amount of the catalyst is constant.

[0003] To maintain the NOx (nitrogen oxides), CO and HC (hydrocarbon) conversion efficiency of the three-way catalyst at a maximum, the catalyst atmosphere must be maintained at the stoichiometric air-fuel ratio. If the oxygen storage amount of the catalyst is maintained constant, oxygen in the exhaust is stored in the catalyst even if the air-fuel ratio of the exhaust flowing into the catalyst temporarily becomes lean, and conversely, oxygen stored in the catalyst is released even if the air-fuel ratio of the exhaust flowing into the catalyst temporarily becomes rich, so the catalyst atmosphere can be maintained at the stoichiometric air-fuel ratio.

[0004] Therefore, in an exhaust purification device performing this type of control, it is required to calculate the oxygen storage amount precisely to maintain the conversion efficiency of the catalyst at a high level, and various methods of computing the oxygen storage amount have been proposed.

SUMMARY OF THE INVENTION

[0005] However, even if the oxygen storage amount can be precisely computed, if the catalyst temperature on engine restart is high such as when the elapsed time from when the engine stopped on the immediately preceding occasion is short, NOx tends to be easily released.

[0006] This is due to the fact that, if the catalyst temperature on engine startup is high, the catalyst has already stored a large amount of oxygen which has entered from the exhaust passage outlet and diffused in the exhaust passage, so the NOx purification performance of the catalyst decreases. When the oxygen storage amount of the catalyst is large, and the air-fuel ratio of the inflowing exhaust is shifted to lean, the catalyst atmosphere cannot be corrected to the stoichiometric air-fuel ratio, and NOx in the exhaust cannot be completely purified.

[0007] It is therefore an object of this invention to suppress the NOx release amount on engine startup in an exhaust purification device which controls the air-fuel ratio of an engine to maintain the oxygen storage amount of a catalyst at a fixed level.

[0008] In order to achieve above object, this invention provides an exhaust purification device for an engine, comprising a first catalyst provided in an exhaust passage of the engine, a front sensor which detects the characteristics of the exhaust flowing into the first catalyst, and a microprocessor programmed to determine whether the engine starts up from a warmed-up state when the engine starts, control the air-fuel ratio of the engine to rich until the exhaust flowing out from the first catalyst has become rich when it is determined that the engine starts up from the warmed-up state, compute the oxygen storage amount of the first catalyst based on the characteristics of the exhaust flowing into the first catalyst, and control the air-fuel ratio of the engine based on the computed oxygen storage amount so that the oxygen storage amount of the first catalyst is a target value.

[0009] According to an aspect of the invention, this invention provides an exhaust purification device for an engine, comprising a first catalyst provided in an exhaust passage of the engine, a second catalyst provided downstream of the first catalyst, a front sensor which detects the characteristics of the exhaust flowing into the first catalyst, and a microprocessor programmed to determine whether the engine starts up from a warmed-up state when the engine starts, control the air-fuel ratio of the engine to rich until the exhaust flowing out from the second catalyst has become rich when it is determined that the engine starts from the warmed-up state, compute the oxygen storage amount of the first catalyst based on the characteristics of the exhaust flowing into the first catalyst, and control the air-fuel ratio of the engine based on the computed oxygen storage amount so that the oxygen storage amount of the first catalyst is a target value.

[0010] The details as well as other features and advantages of this invention are set forth in the remainder of the specification and are shown in the accompanying drawings.

[0011] Strictly speaking, noble metals adsorb oxygen in the molecular state, and oxygen storage materials absorb oxygen as compounds, but in the following description, adsorption and absorption will be collectively referred to as storage.

[0012] Further, the expression "the exhaust air-fuel ratio is rich" means that the oxygen concentration in the exhaust is lower than the oxygen concentration in the exhaust when the engine is running at the stoichiometric air-fuel ratio, and the expression "the exhaust air-fuel ratio is lean" means that the oxygen concentration in the exhaust is higher than the oxygen concentration in the exhaust when the engine is running at the stoichiometric air-fuel ratio. The expression "the exhaust air-fuel ratio is stoichiometric" means that the oxygen concentration of the exhaust is equal to the oxygen concentration in the exhaust when the engine is running at the stoichiometric air-fuel ratio.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Fig. 1 is a schematic diagram of an exhaust purification device according to this invention.

[0014] Fig. 2 is a diagram showing the oxygen storage/release characteristics of a catalyst.

[0015] Fig. 3 is a flowchart showing the details of control performed on engine startup.

[0016] Fig. 4 is a flowchart showing a routine for computing an oxygen storage amount of the catalyst.

[0017] Fig. 5 is a flowchart showing a subroutine for computing an oxygen excess/deficiency amount in exhaust flowing into the catalyst.

[0018] Fig. 6 is a flowchart showing a subroutine for computing an oxygen release rate of a high speed component.

[0019] Fig. 7 is a flowchart showing a subroutine for computing the high speed component of the oxygen storage amount.

[0020] Fig. 8 is a flowchart showing a subroutine for computing a low speed component of the oxygen storage amount.

[0021] Fig. 9 is a flowchart showing a routine for determining a reset condition.

[0022] Fig. 10 is a flowchart showing a routine for performing reset of the computed oxygen storage amount.

[0023] Fig. 11 is a flowchart showing a routine for computing a target air fuel ratio based on the oxygen storage amount.

[0024] Fig. 12 is a diagram showing how a rear oxygen sensor output and high speed component vary when the oxygen storage amount is controlled to be constant.

[0025] Fig. 13 is similar to Fig. 1, but showing a second embodiment of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] Referring to Fig. 1 of the drawings, an exhaust passage 2 of an engine 1 is provided with a catalyst 3, front wide range air-fuel ratio sensor 4 (hereafter referred to as front A/F sensor), rear oxygen sensor 5 and controller 6.

[0027] A throttle 8, and an air flow meter 9 which detects the intake air amount adjusted by the throttle 8, are provided in an intake passage 7 of the engine 1. In addition, a crank angle sensor 12 which detects the engine rotation speed of the engine 1 is provided.

[0028] The catalyst 3 is a catalyst having a three-way catalyst function. The catalyst 3 purifies NOx, HC and CO with maximum efficiency when the catalyst atmosphere is at the stoichiometric air-fuel ratio. The catalyst carrier of the catalyst 3 is coated with an oxygen storage material such as cerium oxide, and the catalyst 3 has the function of storing or releasing oxygen according to the air-fuel ratio of the inflowing exhaust (referred to hereafter as oxygen storage function).

[0029] Here, the oxygen storage amount of the catalyst 3 may be partitioned into a high speed component *HO2* which is stored and released by a noble metal in the catalyst 3 (Pt, Rh, Pd), and a low speed component *LO2* which is stored and released by the oxygen storage material in the catalyst 3. The low speed component *LO2* represents the storage and release of a larger amount of oxygen than the high speed component *HO2*, but its storage/release rate is slower than that of the high speed component *HO2*.

[0030] Further, this high speed component *HO2* and low speed component *LO2* have characteristics as follows:

- When oxygen is stored, oxygen is stored preferentially as the high speed component *HO2*, and begins to be stored as the low speed component *LO2* when the high speed component *HO2* has reached a maximum capacity *HO2MAX* and can no longer be stored.
- When oxygen is released, and the ratio of the low speed component *LO2* to the high speed component *HO2* (*LO2/HO2*) is less than a predetermined value, i.e. when the high speed component is relatively large, oxygen is preferentially released from the high speed component *HO2*, and when the ratio of the low speed component *LO2* to the high speed component *HO2* is larger than the predetermined value, oxygen is released from both the high speed component *HO2* and low speed component *LO2* so that the ratio of the low speed component *LO2* to the high speed component *HO2* does not vary.

[0031] Fig. 2 shows the oxygen storage/release characteristics of the catalyst. The vertical axis shows the high speed component *HO2* (oxygen amount stored in the noble metal) and the horizontal axis shows the low speed component *LO2* (oxygen amount stored in the oxygen storage material).

[0032] In the normal running condition, the low speed component *LO2* is almost zero and only the high speed component *HO2* varies according to the air-fuel ratio of the exhaust flowing into the catalyst as shown as the arrow A_1 in the Figure. The high speed component *HO2* is controlled, for example, to be half of its maximum capacity.

[0033] However, when the engine fuel cut has performed or when the engine has restarted from the warmed-up state (hot restart), the high speed component *HO2* has reached its maximum capacity and oxygen is stored as the low speed component *LO2* (arrow A_2 in Fig. 2). The oxygen storage amount varies from the point X_1 to the point X_2.

[0034] When oxygen is released from the point X_2, oxygen is preferentially released from the high speed component *HO2*. When the ratio of the low speed component *LO2* to the high speed component *HO2* reaches the predetermined value (X_3 in Fig. 2), oxygen is re-

leased from both the high speed component *HO2* and low speed component LO2 so that the ratio of the low speed component *LO2* to the high speed component *HO2* does not vary, i.e., oxygen is released while moving on a straight line *L* shown in the Figure. Here, on the line *L*, the low speed component is from 5 to 15, but preferably approximately 10, relative to the high speed component 1.

[0035] Returning to Fig. 1, the front A/F sensor 4 provided upstream of the catalyst 3 outputs a voltage according to the air-fuel ratio of the exhaust flowing into the catalyst 3. The rear oxygen sensor 5 provided downstream of the catalyst 3 detects whether the exhaust air-fuel ratio downstream of the catalyst 3 is rich or lean with the stoichiometric air-fuel ratio as a threshold value. Here, an economical oxygen sensor was provided downstream of the catalyst 3, but an A/F sensor which can detect the air fuel ratio continuously can be provided instead.

[0036] The cooling water temperature sensor 10 which detects the temperature of the cooling water is fitted to the engine 1. The detected cooling water temperature is used for determining the running state of the engine 1, and also for estimating the catalyst temperature of the catalyst 3.

[0037] The controller 6 comprises a microprocessor, RAM, ROM and I/O interface, and it computes the oxygen storage amount of the catalyst 3 (high speed component *HO2* and low speed component *LO2)* based on the output of the air flow meter 9, front A/F sensor 4 and cooling water temperature sensor 10.

[0038] When the high speed component *HO2* of the computed oxygen storage amount is greater than a predetermined amount (e.g., half the maximum capacity *HO2MAX* of the high speed component), the controller 6 makes the air fuel ratio of the engine 1 rich, makes the air-fuel ratio of the exhaust flowing into the catalyst 3 rich, and decreases the high speed component *HO2*. Conversely, when it is less than the predetermined amount, the controller 6 makes the air fuel ratio of the engine 1 lean, makes the air-fuel ratio of the exhaust flowing into the catalyst 3 lean, increases the high speed component *HO2*, and maintains the high speed component *HO2* of the oxygen storage amount constant.

[0039] When the catalyst temperature on engine startup is high, and a large amount of oxygen has already been stored by the catalyst 3 (hereafter referred to as "hot restart"), in order to release all the oxygen stored by the catalyst 3 to ensure NOx purification performance, a rich shift of the air-fuel ratio is performed until the exhaust downstream of the catalyst 3 has been detected to be rich by the rear oxygen sensor 5.

[0040] A discrepancy may arise between the computed oxygen storage amount and real oxygen storage amount due to computational error, so the controller 6 resets the computational value of the oxygen storage amount with a predetermined timing based on the air-fuel ratio of the exhaust downstream of the catalyst 3, and corrects this discrepancy from the real oxygen storage amount.

[0041] Specifically, when it is determined that the air-fuel ratio downstream of the catalyst 3 is lean based on the output of the rear oxygen sensor 5, it is determined that at least the high speed component *HO2* is maximum, and the high speed component *HO2* is reset to maximum capacity. When it is determined by the rear oxygen sensor 5 that the air fuel ratio downstream of the catalyst 3 is rich, oxygen is no longer being released not only from the high speed component *HO2* but also from the low speed component *LO2*, so the high speed component *HO2* and high speed component *LO2* are reset to minimum capacity.

[0042] Next, the control performed by the controller 6 will be described.

[0043] First, the computation of the oxygen storage amount will be described, followed by resetting of the computational value of the oxygen storage amount, and air-fuel ratio control of the engine 1 based on the oxygen storage amount.

[0044] First, the startup control shown in Fig. 3 (first air-fuel ratio control) is performed, and when startup control has terminated, the routine for computing the oxygen storage amount shown in Fig. 4 is performed repeatedly.

[0045] Fig. 3 shows the details of the startup control. The startup control is performed only once on engine startup, for example, once after it is determined that the engine 1 has started properly.

[0046] According to this, firstly, the cooling water temperature *TWNINT* of the engine 1 on engine startup is detected based on the output of the cooling water temperature sensor 10 (step SS1), and it is determined whether or not the engine 1 has restarted in the state where warmup is complete (hereafter referred to as "warmed-up state"), i.e., whether or not there is a hot restart, by comparing this with a hot restart determining threshold value *TWNHOT* (e.g., 60°C) (step SS2).

[0047] When it is determined that the cooling water temperature *TWNINT* on engine startup is higher than the threshold value *TWNHOT*, and there is a hot restart, the routine proceeds to a step SS3, and a rich shift of the air-fuel ratio the engine 1 is performed to release the oxygen stored by the catalyst 3. The rich shift of the air-fuel ratio of the engine 1 is continued until an output *RO2* of the rear oxygen sensor 5 exceeds a rich determining threshold *RDT*, i.e., until the exhaust downstream of the catalyst 3 becomes rich (steps SS4, SS5).

[0048] When the output *RO2* of the rear oxygen sensor 5 exceeds the rich determining threshold *RDT*, the routine proceeds to a step SS6. At the time when the exhaust downstream of the catalyst 3 changes to rich, it may be considered that all the oxygen stored by the catalyst 3 has been released, so the computed values *HO2*, *LO2* of the high speed component and low speed component of the oxygen storage amount are reset to the minimum capacities *HO2MIN*, *LO2MIN*.

[0049] On the other hand, when the cooling water temperature *TWNINT* on engine startup is lower than the threshold value *TWNHOT* and it is determined that there is no hot restart in the step SS2, startup control is then terminated.

[0050] The determination of the hot restart based on the cooling water temperature of the engine 1 on engine startup, may be performed based on the oil temperature of the engine 1. Alternatively, the temperature of the catalyst 3 on engine startup may be detected by a sensor, or estimated based on various running parameters of the engine 1, and the determination of the hot restart may be performed based on the temperature of the catalyst 3 on engine startup. In this case, it is determined that there is a hot restart when the catalyst temperature on engine startup is higher than a predetermined threshold value (e.g., 300°C).

[0051] When startup control is terminated, the routine for computing the oxygen storage amount of the catalyst 3 shown in Fig. 4 is performed at a predetermined interval.

[0052] According to this routine, first, in a step S1, the outputs of the cooling water temperature sensor 10, crank angle sensor 12 and air flow meter 9 are read as running parameters of the engine 1. In a step S2, a temperature *TCAT* of the catalyst 3 is estimated based on these parameters. In a step S3, by comparing the estimated catalyst temperature *TCAT* and a catalyst activation temperature *TACTo* (e.g., 300°C), it is determined whether or not the catalyst 3 has activated.

[0053] When it is determined that the catalyst activation temperature *TACTo* has been reached, the routine proceeds to a step S4 to compute the oxygen storage amount of the catalyst 3. When it is determined that the catalyst activation temperature *TACTo* has not been reached, processing is terminated assuming that the catalyst 3 does not store or release oxygen.

[0054] In the step S4, a subroutine (Fig. 5) for computing an oxygen excess/deficiency amount *O2IN* is performed, and the oxygen excess/deficiency amount of the exhaust flowing into the catalyst 3 is computed. In a step S5, a subroutine (Fig. 6) for computing an oxygen release rate A of the high speed component of the oxygen storage amount is performed, and the oxygen release rate A of the high speed component is computed..

[0055] Further, in a step S6, a subroutine (Fig. 7) for computing the high speed component *HO2* of the oxygen storage amount is performed, and the high speed component *HO2* and an oxygen amount *OVERFLOW* overflowing into the low speed component *LO2* without being stored as the high speed component *HO2*, are computed based on the oxygen excess/deficiency amount *O2IN* and the oxygen release rate A of the high speed component.

[0056] In a step S7, it is determined whether or not all of the oxygen excess/deficiency amount *O2IN* flowing into the catalyst 3 has been stored as the high speed component *HO2* based on the overflow oxygen amount *OVERFLOW.* When all of the oxygen excess/deficiency amount *O2IN* has been stored as the high speed component (*OVERFLOW* = 0), processing is terminated. In other cases, the routine proceeds to a step S8, a subroutine (Fig. 8) is performed for computing the low speed component *LO2,* and the low speed component *LO2* is computed based on the overflow oxygen amount *OVERFLOW* overflowing from the high speed component *HO2.*

[0057] Here, the catalyst temperature *TCAT* is estimated from the cooling water temperature of the engine 1, the engine load and the engine rotation speed, but a temperature sensor 11 may also be attached to the catalyst 3 as shown in Fig. 1, and the temperature of the catalyst 3 measured directly.

[0058] When the catalyst temperature *TCAT* is less than the activation temperature *TACTo*, the oxygen storage amount is not computed, but the step S3 may be eliminated, and the effect of the catalyst temperature *TCAT may* be reflected in the oxygen release rate *A* of the high speed component or an oxygen storage/release rate B of the low speed component, described later.

[0059] Next, a subroutine performed from steps S4 to S6 and in the step S8 will be described.

[0060] Fig. 5 shows the subroutine for computing the oxygen excess/deficiency amount *O2IN* of the exhaust flowing into the catalyst 3. In this subroutine, the oxygen excess/deficiency amount *O2IN* of the exhaust flowing into the catalyst 3 is computed based on the air-fuel ratio of the exhaust upstream of the catalyst 3 and the intake air amount of the engine 1.

[0061] First, in a step S11, the output of the front A/F sensor 4 and the output of the air flow meter 9 are read.

[0062] Next, in a step S12, the output of the front A/F sensor 4 is converted to an excess/deficiency oxygen concentration *FO2* of the exhaust flowing into the catalyst 3 using a predetermined conversion table. Here, the excess/deficiency oxygen concentration *FO2* is a relative concentration based on the oxygen concentration at the stoichiometric air-fuel ratio. If the exhaust air-fuel ratio is equal to the stoichiometric air-fuel ratio, it is zero, if it is richer than the stoichiometric air-fuel ratio it is negative, and if it is leaner than the stoichiometric air-fuel ratio, it is positive.

[0063] In a step S13, the output of the air flow meter 9 is converted to an intake air amount Q using a predetermined conversion table, and in a step S14, the intake air amount Q is multiplied by the excess/deficiency oxygen concentration *FO2* to compute the excess/deficiency oxygen amount *O2IN* of the exhaust flowing into the catalyst 3.

[0064] As the excess/deficiency oxygen concentration FO2 has the above characteristics, the excess/deficiency oxygen amount *O2IN* is zero when the exhaust flowing into the catalyst 3 is at the stoichiometric air-fuel ratio, a negative value when it is rich, and a positive val-

ue when it is lean.

[0065] Fig. 6 shows a subroutine for computing the oxygen release rate A of the high speed component of the oxygen storage amount. In this subroutine, as the oxygen release rate of the high speed component *HO2* is affected by the low speed component LO2, the oxygen release rate A of the high speed component is computed according to the low speed component *LO2*.

[0066] First, in a step S21, it is determined whether or not a ratio *LO2/HO2* of low speed component relative to the high speed component is less than a predetermined value AR. When it is determined that the ratio *LO2/HO2* is less than the predetermined value AR, i.e., when the high speed component *HO2* is relatively larger than the low speed component *LO2*, the routine proceeds to a step S22, and the oxygen release rate A of the high speed component is set to 1.0 expressing the fact that oxygen is released first from the high speed component *HO2*.

[0067] On the other hand, when it is determined that the ratio *LO2/HO2* is not less than the predetermined value AR, oxygen is released from the high speed component *HO2* and the low speed component *LO2* so that the ratio of the low speed component *LO2* to the high speed component *HO2* does not vary. The routine then proceeds to a step S23, and a value of the oxygen release rate A of the high speed component is computed which does not cause the ratio *LO2/HO2* to vary.

[0068] Fig. 7 shows a subroutine for computing the high speed component *HO2* of the oxygen storage amount. In this subroutine, the high speed component *HO2* is computed based on the oxygen excess/deficiency amount *O2IN* of the exhaust flowing into the catalyst 3 and the oxygen release rate A of the high speed component.

[0069] First, it is determined in a step S31 whether or not the high speed component *HO2* is being stored or released based on the oxygen excess/deficiency amount *O2IN*.

[0070] When the air-fuel ratio of the exhaust flowing into the catalyst 3 is lean and the oxygen excess/deficiency amount *O2IN* is larger than zero, it is determined that the high speed component *HO2* is being stored, the routine proceeds to a step S32, and the high speed component *HO2* is computed from the following equation (1):

$$HO2 = HO2z + O2IN \qquad (1)$$

where: *HO2z* = value of high speed component *HO2* on immediately preceding occasion.

[0071] On the other hand, when it is determined that the oxygen excess/deficiency amount *O2IN* is less than zero and the high speed component is being released, the routine proceeds to a step S33, and the high speed component *HO2* is computed from the following equation (2):

$$HO2 = HO2z + O2IN \times A \qquad (2)$$

where: *A*= oxygen release rate of high speed component *HO2*.

[0072] In steps S34, S35, it is determined whether or not the computed *HO2* exceeds the maximum capacity *HO2MAX* of the high speed component, or whether it is not less than a minimum capacity *HO2MIN* (= 0).

[0073] When the high speed component *HO2* is greater than the maximum capacity *HO2MAX*, the routine proceeds to a step S36, the overflow oxygen amount (excess amount) *OVERFLOW* flowing out without being stored as the high speed component *HO2* is computed from the following equation (3):

$$OVERFLOW = HO2 - HO2MAX \qquad (3),$$

and the high speed component *HO2* is limited to the maximum capacity *HO2MAX*.

[0074] When the high speed component *HO2* is less than the minimum capacity *HO2MIN*, the routine proceeds to a step S37, the overflow oxygen amount (deficiency amount) *OVERFLOW* which was not stored as the high speed component *HO2* is computed by the following equation (4):

$$OVERFLOW = HO2 - HO2MIN \qquad (4),$$

and the high speed component *HO2* is limited to the minimum capacity *HO2MIN*. Here, zero is given as the minimum capacity *HO2MIN*, so the oxygen amount which is deficient when all the high speed component HO2 has been released is computed as a negative overflow oxygen amount.

[0075] When the high speed component *HO2* lies between the maximum capacity *HO2MAX* and minimum capacity *HO2MIN*, the oxygen excess/deficiency amount *O2IN* of the exhaust flowing into the catalyst 3 is all stored as the high speed component HO2, and zero is set to the overflow oxygen amount *OVERFLOW*.

[0076] Here, when the high speed component *HO2* is greater than the maximum capacity *HO2MAX* or less than the minimum capacity *HO2MIN*, the overflow oxygen amount *OVERFLOW* which has overflowed from the high speed component *HO2* is stored as the low speed component *LO2*.

[0077] Fig. 8 shows a subroutine for computing the low speed component *LO2* of the oxygen storage amount. In this subroutine, the low speed component *LO2* is computed based on the overflow oxygen amount *OVERFLOW* which has overflowed from the high speed component *HO2*.

[0078] According to this, in a step S41, the low speed component *LO2* is computed by the following equation (5):

$$LO2 = LO2z + OVERFLOW \times B \qquad (5)$$

where: $LO2z$ = immediately preceding value of low speed component $LO2$, and B = oxygen storage/release rate of low speed component.

[0079] Here, the oxygen storage/release rate *B* of the low speed component is set to a positive value less than 1, but actually has different characteristics for storage and release. Further, the real storage/release rate is affected by the catalyst temperature *TCAT* and the low speed component *LO2*, so the storage rate and release rate can be set to vary independently. In this case, when the overflow oxygen amount *OVERFLOW* is positive, oxygen is in excess, and the oxygen storage rate at this time is set to for example a value which is larger the higher the catalyst temperature *TCAT* or the smaller the low speed component LO2. Also, when the overflow oxygen amount *OVERFLOW* is negative, oxygen is deficient, and the oxygen release rate at this time may for example be set to a value which is larger the higher the catalyst temperature *TCAT* or the larger the low speed component *LO2*.

[0080] In steps S42, S43, in the same way as when the high speed component *HO2* is computed, it is determined whether or not the computed low speed component *LO2* has exceeded a maximum capacity *LO2MAX* or is less than a minimum capacity *LO2MIN* (= 0).

[0081] When maximum capacity *LO2MAX* is exceeded, the routine proceeds to a step S44, an oxygen excess/deficiency amount *O2OUT* which has overflowed from the low speed component *LO2* is computed from the following equation (6):

$$LO2OUT = LO2 - LO2MAX \qquad (6)$$

and the low speed component LO2 is limited to the maximum capacity *LO2MAX*. The oxygen excess/deficiency amount *O2OUT* flows out downstream of the catalyst 3.

[0082] When the low speed component *LO2* is less than the minimum capacity, the routine proceeds to a step S45, and the low speed component *LO2* is limited to the minimum capacity *LO2MIN*.

[0083] Next, the resetting of the computed value of the oxygen storage amount performed by the controller 6 will be described. By resetting the computed value of the oxygen storage amount under predetermined conditions, computational errors which have accumulated so far are eliminated, and the computational precision of the oxygen storage amount can be improved.

[0084] Fig. 9 shows the details of a routine for determining the reset condition. This routine determines whether or not a condition for resetting the oxygen storage amount (high speed component *HO2* and low speed component LO2) holds from the exhaust air-fuel ratio downstream of the catalyst 3, and sets a flag *Frich* and a flag *Flean*.

[0085] First, in a step S51, the output of the rear oxygen sensor 5 which detects the exhaust air-fuel ratio downstream of the catalyst 3 is read. Subsequently, in a step S52, the rear oxygen sensor output *RO2* is compared with a lean determining threshold *LDT*, and in a step S53, the rear oxygen sensor output *RO2* is compared with the rich determining threshold *RDT*.

[0086] As a result of these comparisons, when the rear oxygen sensor output *RO2* is less than the lean determining threshold *LDT*, the routine proceeds to a step S54, and the flag *Flean* is set to "1" showing that the lean reset condition for the oxygen storage amount holds. When the rear oxygen sensor output *RO2* exceeds the rich determining threshold *RDT*, the routine proceeds to a step S55, and the flag *Frich* is set to "1" showing that the rich reset condition for the oxygen storage amount holds.

[0087] When the rear oxygen sensor output RO2 lies between the lean determining threshold *LDT* and rich determining threshold *RDT*, the routine proceeds to a step S56, and the flags *Flean* and *Frich* are set to "0" showing that the lean reset condition and rich reset condition do not hold.

[0088] Fig. 10 shows a routine for resetting the oxygen storage amount.

[0089] According to this, in steps S61, S62, it is determined whether or not the lean reset conditions or rich reset conditions hold based on the variation of the values of the flags *Flean* and *Frich*.

[0090] When the flag *Flean* changes from "0" to "1", and it is determined that lean reset conditions hold, the routine proceeds to a step S63, and the high speed component *HO2* of the oxygen storage amount is reset to the maximum capacity *HO2MAX*. At this time, resetting of the low speed component LO2 is not performed. On the other hand, when the flag *Frich* changes from "0" to "1", and it is determined that rich reset conditions hold, the routine proceeds to a step S64, and the high speed component *HO2* and low speed component *LO2* of the oxygen storage amount are respectively reset to the minimum capacities *HO2MIN*, *LO2MIN*.

[0091] The reason why resetting is performed under these conditions is that as the oxygen storage rate of the low speed component *LO2* is slow, oxygen overflows downstream of the catalyst even if the low speed component *LO2* has not reached maximum capacity when the high speed component *HO2* reaches maximum capacity, and when the exhaust air-fuel ratio downstream of the catalyst becomes lean, it may be considered that at least the high speed component *HO2* has reached maximum capacity.

[0092] When the exhaust air fuel ratio downstream of the catalyst becomes rich, oxygen is not released from the low speed component *LO2* which is released slowly. Therefore, it may be considered that the high speed component *HO2* and low speed component *LO2* are both not being stored and are at minimum capacity.

[0093] Next, the air-fuel ratio control performed by the controller 6 (oxygen storage amount constant control) will be described.

[0094] Fig. 11 shows a routine for computing a target air fuel ratio based on the oxygen storage amount (second air-fuel ratio control).

[0095] According to this, in a step S71, the high speed component *HO2* of the present oxygen storage amount is read. In a step S72, a deviation *DHO2* (= oxygen excess/deficiency amount required by catalyst 3) between the current high speed component *HO2* and a target value *TGHO2* of the high speed component, is computed. The target value *TGHO2* of the high speed component is set to, for example, half of the maximum capacity *HO2MAX* of the high speed component.

[0096] In a step S73, the computed deviation *DHO2* is converted to an air-fuel ratio equivalent value, and a target air-fuel ratio *T-A/F* of the engine 1 is set.

[0097] Therefore, according to this routine, when the high speed component *HO2* of the oxygen storage amount does not reach a target amount, the target air fuel ratio of the engine 1 is set to lean, and the oxygen storage amount (high speed component *HO2)* is increased. On the other hand, when the high speed component *HO2* exceeds the target amount, the target air fuel ratio of the engine 1 is set to rich, and the oxygen storage amount (high speed component *HO2)* is decreased.

[0098] Next, the overall action performed by the above control will be described.

[0099] In the exhaust purification device according to this invention, when the engine 1 starts, the startup control is first performed.

[0100] When it is determined that there is a hot restart from the cooling water temperature on engine startup, the air-fuel ratio of the engine 1 is shifted to rich until the exhaust downstream of the catalyst 3 becomes rich and the oxygen stored by the catalyst 3 is all released.

[0101] When the oxygen amount already stored by the catalyst 3 is large in a hot restart, the catalyst atmosphere cannot be corrected to the stoichiometric air-fuel ratio when the air-fuel ratio of the exhaust flowing into the catalyst 3 has shifted to lean, and if the vehicle were to continue running, the NOx release amount would increase. However, according to this invention, in a hot restart, the air-fuel ratio of the engine 1 is shifted to rich until the exhaust downstream of the catalyst 3 becomes rich, and all the oxygen stored by the catalyst 3 is released, and so the amount of NOx released on engine startup is suppressed. Further, the initial value of the oxygen storage amount is zero and it corresponds to the real oxygen storage amount, so the subsequent computational precision of the oxygen storage amount can be enhanced.

[0102] When the above startup control is terminated, computation of the oxygen storage amount of the catalyst 3 begins, and air fuel ratio control of the engine 1 is performed so that the oxygen storage amount of the catalyst 3 is constant to maintain the conversion efficiency of the catalyst 3 at a maximum.

[0103] The oxygen storage amount of the catalyst 3 is estimated based on the air-fuel ratio of the exhaust gas flowing into the catalyst 3 and the intake air amount, and computation of the oxygen storage amount is divided into the high speed component *HO2* and low speed component *LO2* according to the actual characteristics.

[0104] Specifically, the computation is performed assuming that when oxygen is stored, the high speed component *HO2 is* preferentially stored, and the low speed component *LO2* begins to be stored when the high speed component *HO2* can no longer be stored. The computation also assumes that when oxygen is released, when the ratio *(LO2/HO2)* of the low speed component *LO2* and high speed component *HO2 is* less than the predetermined value AR, oxygen is preferentially released from the high speed component *HO2,* and when the ratio *LO2/HO2* reaches the predetermined value AR, oxygen is released from both the low speed component *LO2* and high speed component *HO2* to maintain this ratio *LO2/HO2.*

[0105] When the high speed component *HO2* of the computed oxygen storage amount is larger than the target value, the controller 6 decreases the high speed component by controlling the air-fuel ratio of the engine 1 to rich, and when it is less than the target value, the high speed component *HO2 is* increased by controlling the air-fuel ratio to lean.

[0106] As a result, the high speed component *HO2* of the oxygen storage amount is maintained at the target value, and even if the air-fuel ratio of the exhaust flowing into the catalyst 3 shifts from the stoichiometric air-fuel ratio, oxygen is immediately stored as the high speed component *HO2* or immediately released as the high speed component *HO2* which has a high responsiveness, the catalyst atmosphere is corrected to the stoichiometric air-fuel ratio, and the conversion efficiency of the catalyst 3 is maintained at a maximum.

[0107] Further, if computational errors accumulate, the computed oxygen storage amount shifts from the real oxygen storage amount, however the oxygen storage amount (high speed component *HO2* and low speed component *LO2)* is reset with a timing at which the exhaust downstream of the catalyst 3 becomes rich or lean, and any discrepancy between the computed value and real oxygen storage amount is corrected.

[0108] Fig. 12 shows how the high speed component *HO2* varies when the above oxygen storage amount constant control is performed.

[0109] In this case, at the time *t1*, the output of the rear oxygen sensor 5 becomes less than the lean determining threshold and lean reset conditions hold, so the high speed component *HO2* is reset to the maximum capacity *HO2MAX.* However, the low speed component LO2 is not necessarily a maximum at this time, so reset of the low speed component is not performed, not shown.

[0110] At times t2, *t3*, the output of the rear oxygen sensor 5 becomes greater than the rich determining threshold and rich reset conditions hold, so the high speed component *HO2* of the oxygen storage amount is reset to the minimum capacity (= 0). The low speed component *LO2* at this time is also reset to the minimum capacity, not shown.

[0111] Thus, resetting of the computed values of the oxygen storage amount is performed with a timing at which the air-fuel ratio of the exhaust downstream of the catalyst 3 becomes rich or lean, and as a result of the discrepancy from the real oxygen storage amount being corrected, the computational precision of the oxygen storage amount of the catalyst is further enhanced, the precision of air-fuel ratio control for maintaining the oxygen storage amount constant is increased, and the conversion efficiency of the catalyst is maintained at a high level.

[0112] Fig. 13 shows a second embodiment of this invention.

[0113] A second catalyst 13 (e.g., HC adsorption catalyst having a three-way catalyst function) is further provided downstream of the catalyst 3.

[0114] In this case, if the air-fuel ratio of the engine 1 is shifted to rich until it is detected that the exhaust downstream of the second catalyst has become rich by a second oxygen sensor 14 provided downstream of the second catalyst 13 in steps SS4, SS5 of Fig. 3, the oxygen stored by the catalyst 3 and the second catalyst 13 can be released at the same time. In this way, the NOx purification performance not only of the catalyst 3 but also of the second catalyst 13 situated further downstream can be maintained, and the NOx release amount immediately after startup can be suppressed.

[0115] According also to this embodiment, the oxygen storage amount of the catalyst 3 is computed separately as the high speed component and the low speed component by the processing shown from Fig. 4 to Fig. 8, and the air-fuel ratio of the engine 1 is controlled so that the high speed component is a target value (e.g., half of the maximum capacity *HO2MAX*).

[0116] Identical processing to that shown from Fig. 4 to Fig. 8 is performed for the second catalyst 13, and when the oxygen storage amount of the second catalyst 13 is computed separately for the high speed component and the low speed component, if the high speed component and low speed component of the oxygen storage amounts in the catalyst 3 and second catalyst 13 are respectively reset to the minimum capacities when it is detected by the second sensor 14, by an identical processing to the reset processing shown in Fig. 9 and Fig. 10, that the exhaust downstream of the second catalyst 13 has become rich, computational errors in the oxygen storage amounts of the catalyst 3 and second catalyst 13 can be eliminated.

[0117] The entire contents of Japanese Patent Applications P2000-44725 (filed February 22, 2000) and P2001-38145 (filed February 15, 2001) are incorporated herein by reference.

[0118] Although the invention has been described above by reference to a certain embodiment of the invention, the invention is not limited to the embodiment described above. Modifications and variations of the embodiments described above will occur to those skilled in the art, in light of the above teachings. The scope of the invention is defined with reference to the following claims.

Claims

1. An exhaust purification device for an engine (1), comprising:

    a first catalyst (3) provided in an exhaust passage (2) of the engine (1),
    a front sensor (4) which detects the characteristics of the exhaust flowing into the first catalyst (3), and
    a microprocessor (6) programmed to:

        determine whether the engine (1) starts up from a warmed-up state when the engine (1) starts,
        control the air-fuel ratio of the engine (1) to rich until the exhaust flowing out from the first catalyst (3) has become rich when it is determined that the engine (1) starts up from the warmed-up state,
        compute the oxygen storage amount of the first catalyst (3) based on the characteristics of the exhaust flowing into the first catalyst (3), and
        control the air-fuel ratio of the engine (1) based on the computed oxygen storage amount so that the oxygen storage amount of the first catalyst (3) is a target value.

2. An exhaust purification device as defined in Claim 1, wherein the microprocessor (6) is further programmed to determine that the engine (1) starts up from the warmed-up state when the cooling fluid temperature of the engine (1) on engine startup is higher than a predetermined temperature.

3. An exhaust purification device as defined in Claim 1, wherein the microprocessor (6) is further programmed to determine that the engine (1) starts up from the warmed-up state when the temperature of the catalyst (3) on engine startup is higher than a predetermined temperature.

4. An exhaust purification device as defined in Claim 1, further comprising a first rear sensor (5) which detects the characteristics of the exhaust flowing out of the first catalyst (3).

5. An exhaust purification device as defined in Claim 1, wherein the microprocessor (6) is further programmed to compute the oxygen storage amount of the first catalyst (3) separately for a high speed component which has a fast storage/release rate and a low speed component which has a slower storage/release rate than the high speed component.

6. An exhaust purification device as defined in Claim 5, wherein the microprocessor (6) is further programmed to reset the computed values of the high speed component and low speed component to their minimum capacities when the exhaust flowing out of the first catalyst (3) has become rich.

7. An exhaust purification device for an engine (1), comprising:

a first catalyst (3) provided in an exhaust passage (2) of the engine (1),
a second catalyst (13) provided downstream of the first catalyst (3),
a front sensor (4) which detects the characteristics of the exhaust flowing into the first catalyst (3), and
a microprocessor (6) programmed to:

determine whether the engine (1) starts up from a warmed-up state when the engine (1) starts,
control the air-fuel ratio of the engine (1) to rich until the exhaust flowing out from the second catalyst (14) has become rich when it is determined that the engine starts from the warmed-up state,
compute the oxygen storage amount of the first catalyst (3) based on the characteristics of the exhaust flowing into the first catalyst (3), and
control the air-fuel ratio of the engine (1) based on the computed oxygen storage amount so that the oxygen storage amount of the first catalyst (3) is a target value.

8. An exhaust purification device as defined in Claim 7, further comprising a second rear sensor (14) which detects the characteristics of the exhaust flowing out of the second catalyst (13).

9. An exhaust purification device for an engine (1), comprising:

a first catalyst (3) provided in an exhaust passage (2) of the engine (1),
means for detecting the characteristics of the exhaust flowing into the first catalyst (3),
means for determining whether the engine (1) starts up from a warmed-up state when the engine (1) starts,
means for controlling the air-fuel ratio of the engine (1) to rich until the exhaust flowing out from the first catalyst (3) has become rich when it is determined that the engine (1) starts up from the warmed-up state,
means for computing the oxygen storage amount of the first catalyst (3) based on the characteristics of the exhaust flowing into the first catalyst (3), and
means for controlling the air-fuel ratio of the engine (1) based on the computed oxygen storage amount so that the oxygen storage amount of the first catalyst (3) is a target value.

10. An exhaust purification device for an engine (1), comprising:

a first catalyst (3) provided in an exhaust passage (2) of the engine (1),
a second catalyst (13) provided downstream of the first catalyst (3),
means for detecting the characteristics of the exhaust flowing into the first catalyst (3),
means for determining whether the engine (1) starts up from a warmed-up state when the engine (1) starts,
means for controlling the air-fuel ratio of the engine (1) to rich until the exhaust flowing out from the second catalyst (14) has become rich when it is determined that the engine starts from the warmed-up state,
means for computing the oxygen storage amount of the first catalyst (3) based on the characteristics of the exhaust flowing into the first catalyst (3), and
means for controlling the air-fuel ratio of the engine (1) based on the computed oxygen storage amount so that the oxygen storage amount of the first catalyst (3) is a target value.

11. A method for controlling an air-fuel ratio of an engine (1) which has a first catalyst (3) in an exhaust passage (2) of the engine (1), comprising:

determining whether the engine (1) starts up from a warmed-up state when the engine (1) starts,
controlling the air-fuel ratio of the engine (1) to rich until the exhaust flowing out from the first catalyst (3) has become rich when it is determined that the engine (1) starts up from the warmed-up state,
computing the oxygen storage amount of the first catalyst (3) based on the characteristics of the exhaust flowing into the first catalyst (3), and

controlling the air-fuel ratio of the engine (1) based on the computed oxygen storage amount so that the oxygen storage amount of the first catalyst (3) is a target value.

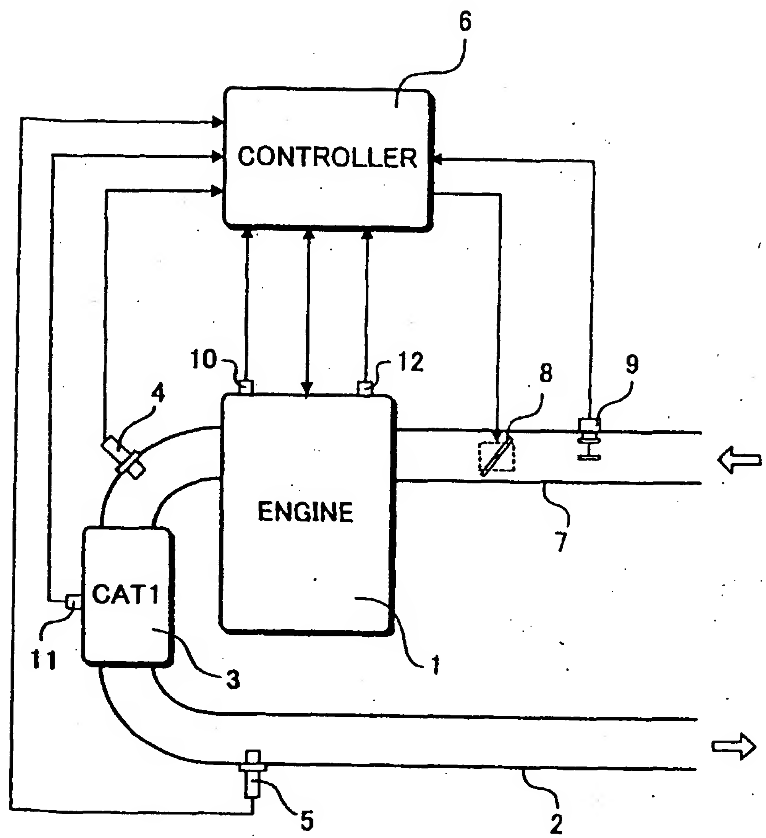

FIG. 1

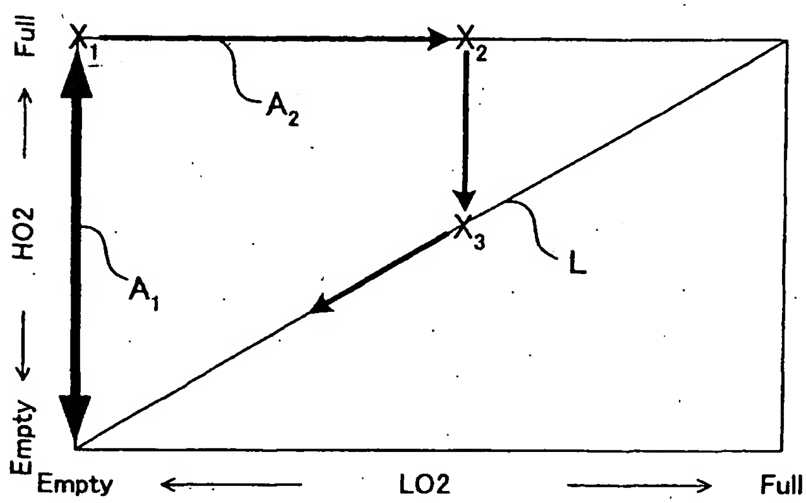

FIG.2

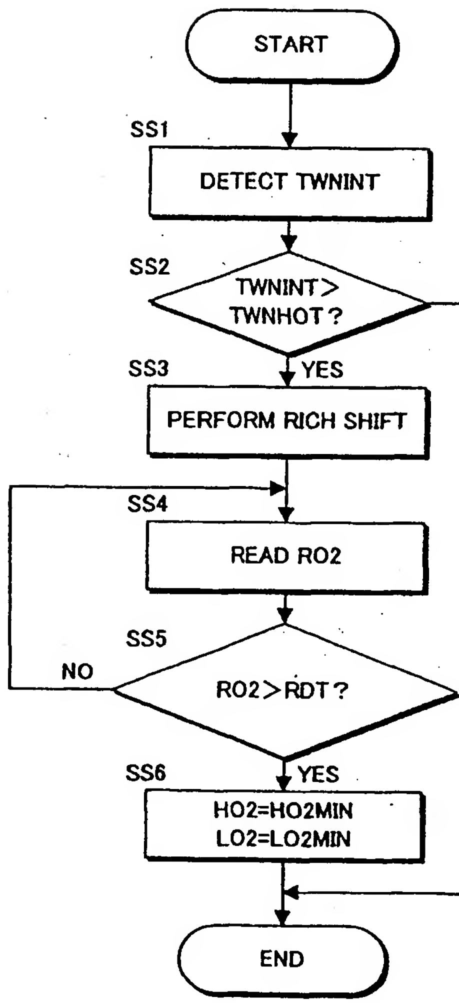
START
SS1
DETECT TWNINT
SS2
TWNINT>
TWNHOT ?
NO
SS3
YES
PERFORM RICH SHIFT
SS4
READ RO2
SS5
NO
RO2>RDT ?
SS6
YES
HO2=HO2MIN
LO2=LO2MIN
END

FIG.3

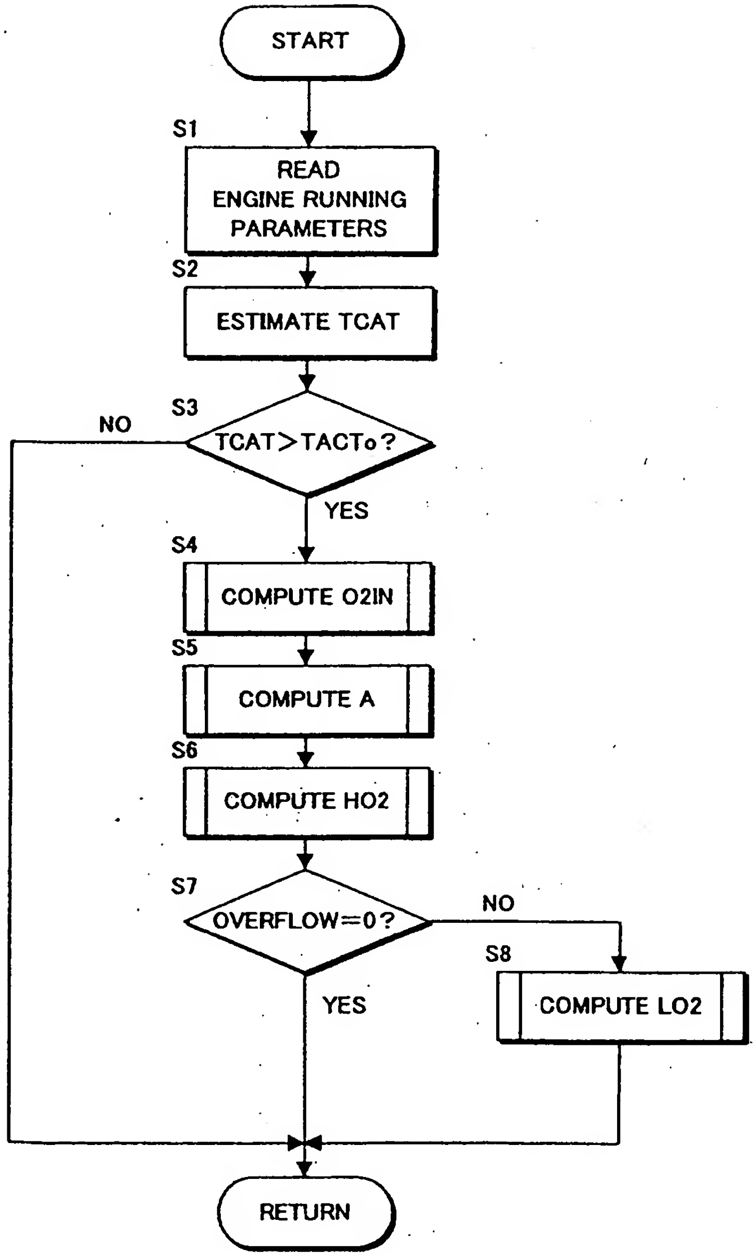
START
S1
READ
ENGINE RUNNING
PARAMETERS
S2
ESTIMATE TCAT
S3
NO
TCAT>TACTo?
YES
S4
COMPUTE O2IN
S5
COMPUTE A
S6
COMPUTE HO2
S7
OVERFLOW=0?
NO
S8
COMPUTE LO2
YES
RETURN

FIG.4

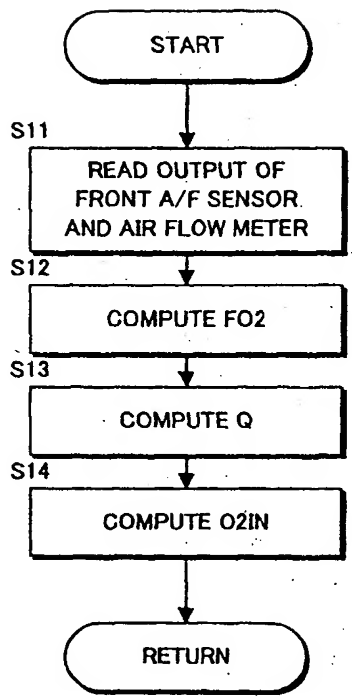
START
S11
READ OUTPUT OF FRONT A/F SENSOR AND AIR FLOW METER
S12
COMPUTE FO2
S13
COMPUTE Q
S14
COMPUTE O2IN
RETURN

FIG.5

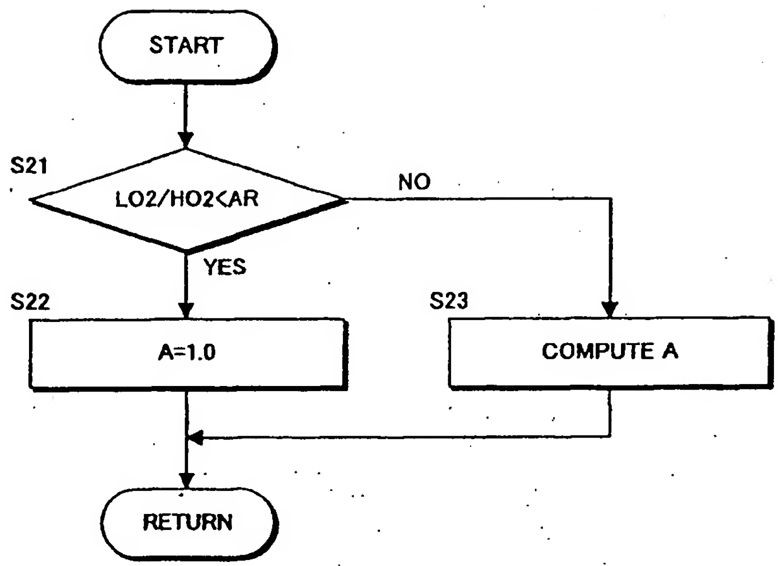

FIG.6

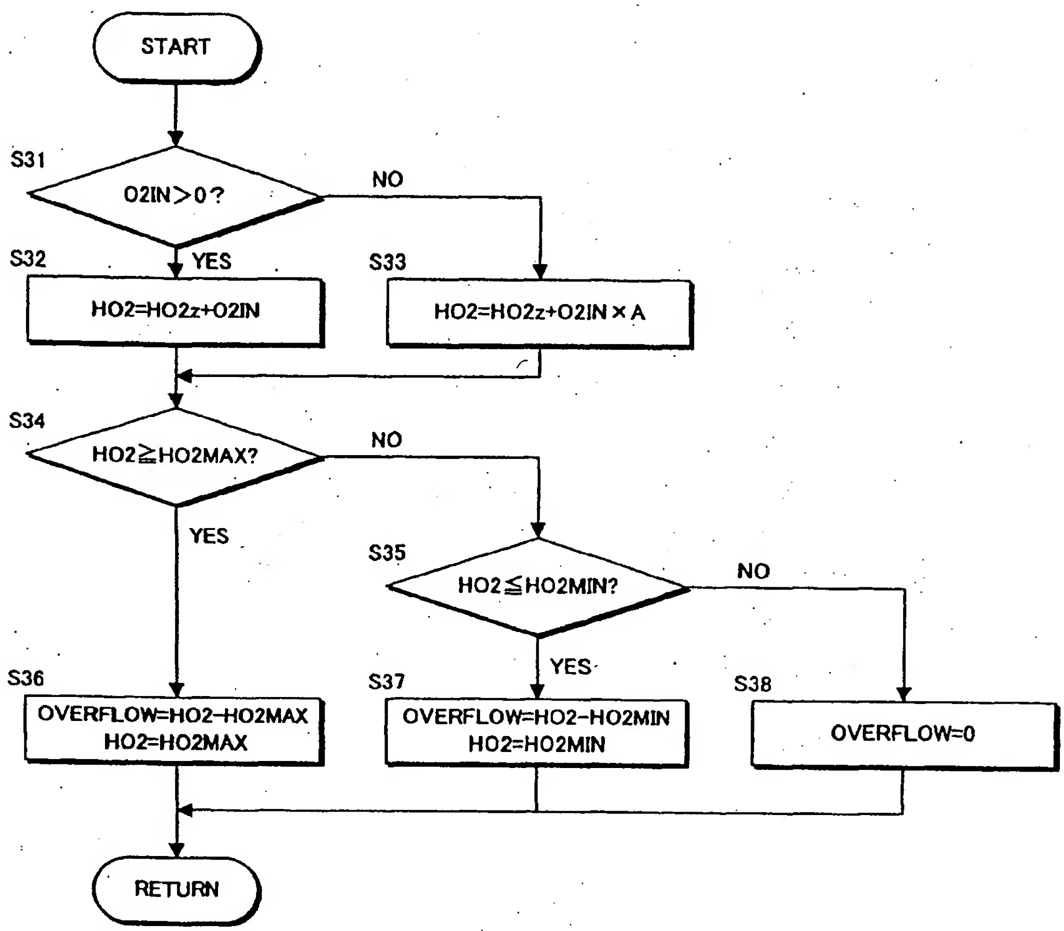
START
S31
O2IN>0?
NO
S32
YES
S33
HO2=HO2z+O2IN
HO2=HO2z+O2IN×A
S34
HO2≧HO2MAX?
NO
YES
S35
HO2≦HO2MIN?
NO
S36
YES
S37
S38
OVERFLOW=HO2−HO2MAX
HO2=HO2MAX
OVERFLOW=HO2−HO2MIN
HO2=HO2MIN
OVERFLOW=0
RETURN

FIG.7

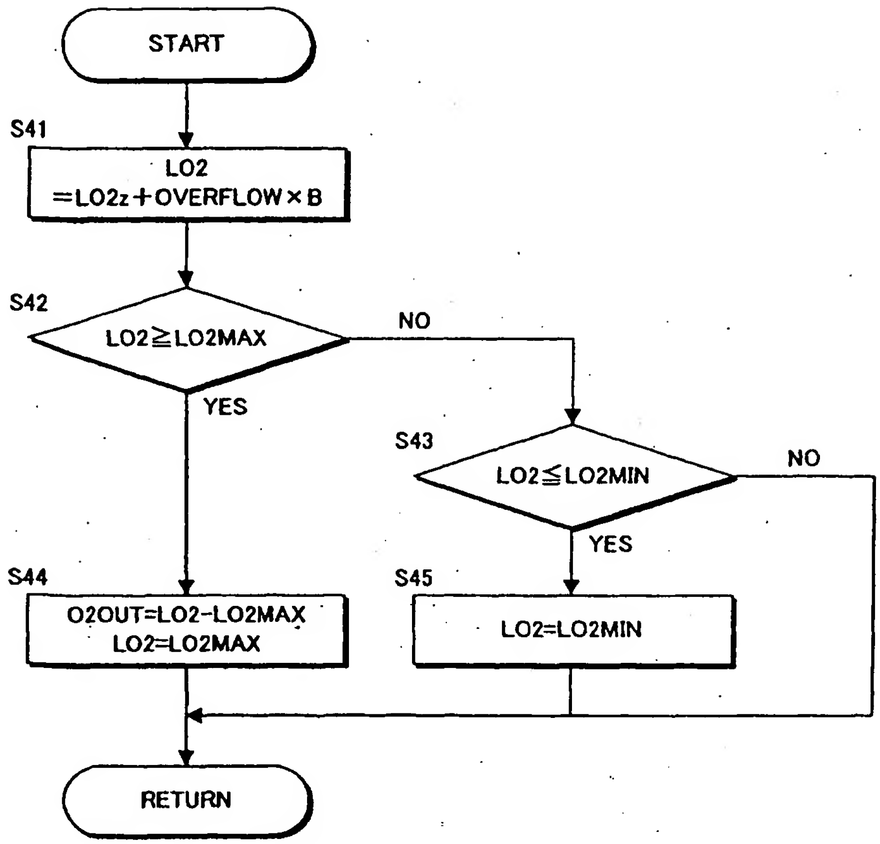
START
S41
LO2
=LO2z+OVERFLOW×B
S42
LO2≧LO2MAX
NO
YES
S43
LO2≦LO2MIN
NO
YES
S44
O2OUT=LO2-LO2MAX
LO2=LO2MAX
S45
LO2=LO2MIN
RETURN

FIG.8

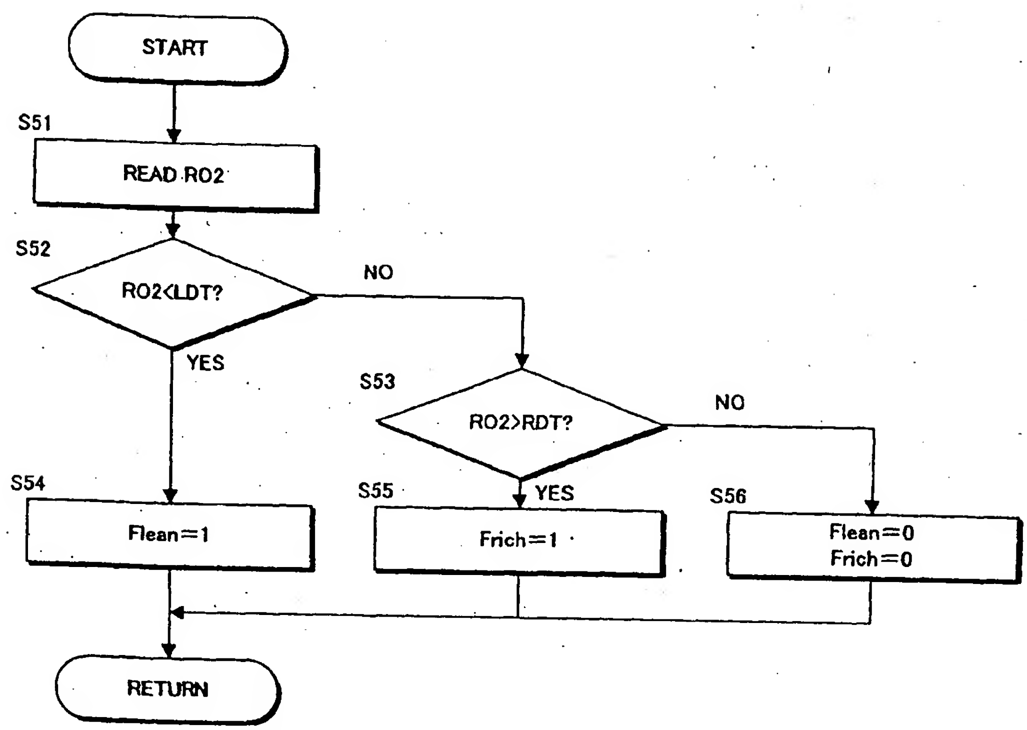
START
S51
READ RO2
S52
RO2<LDT?
NO
YES
S53
RO2>RDT?
NO
S54
S55
YES
S56
Flean=1
Frich=1
Flean=0
Frich=0
RETURN

FIG.9

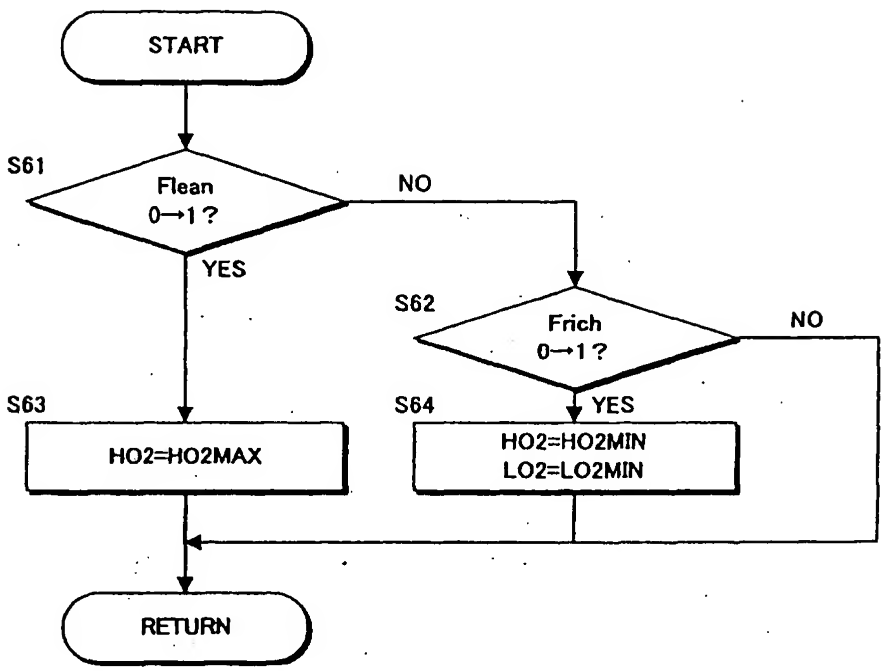
START
S61
Flean
0→1 ?
NO
YES
S62
Frich
0→1 ?
NO
S63
HO2=HO2MAX
S64
YES
HO2=HO2MIN
LO2=LO2MIN
RETURN

FIG. 10

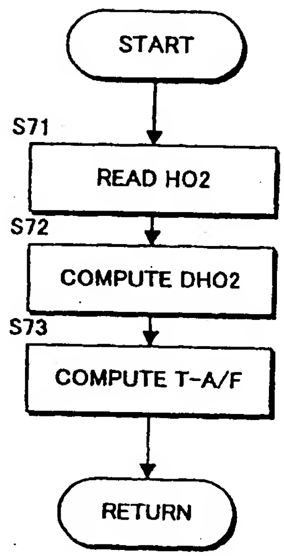

FIG. 11

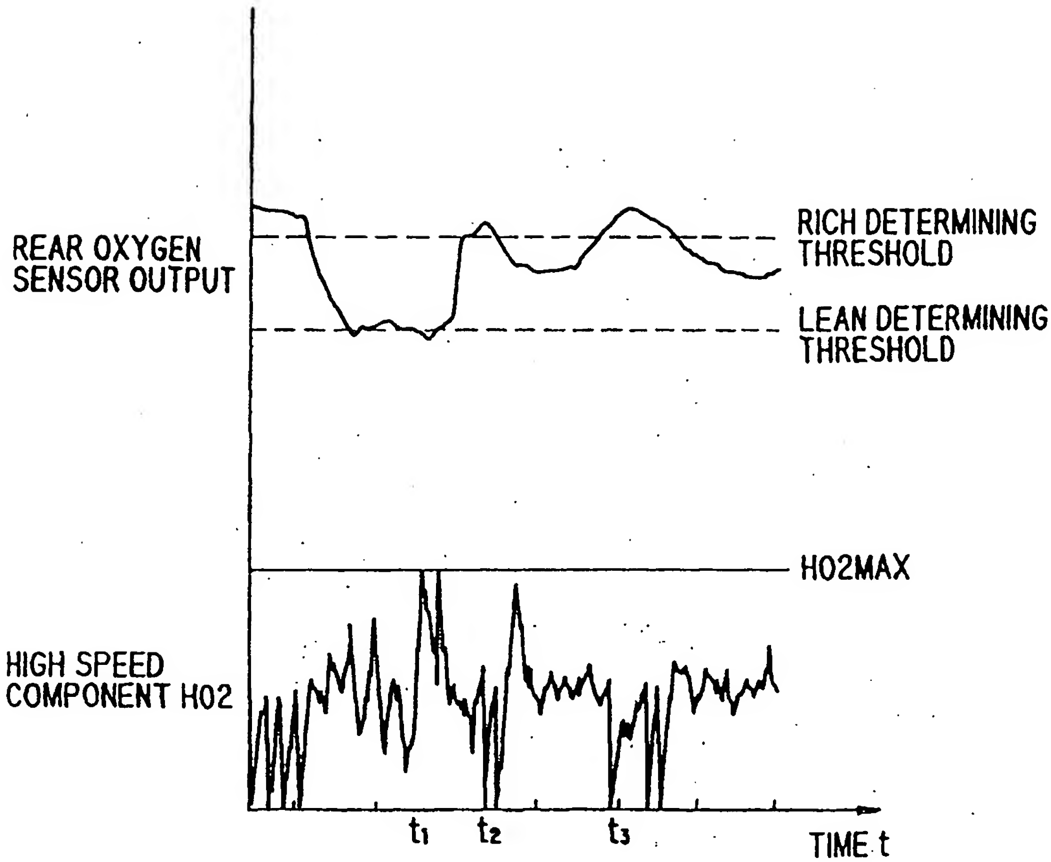
RICH DETERMINING THRESHOLD
REAR OXYGEN SENSOR OUTPUT
LEAN DETERMINING THRESHOLD
H02MAX
HIGH SPEED COMPONENT H02
t1
t2
t3
TIME t

FIG. 12

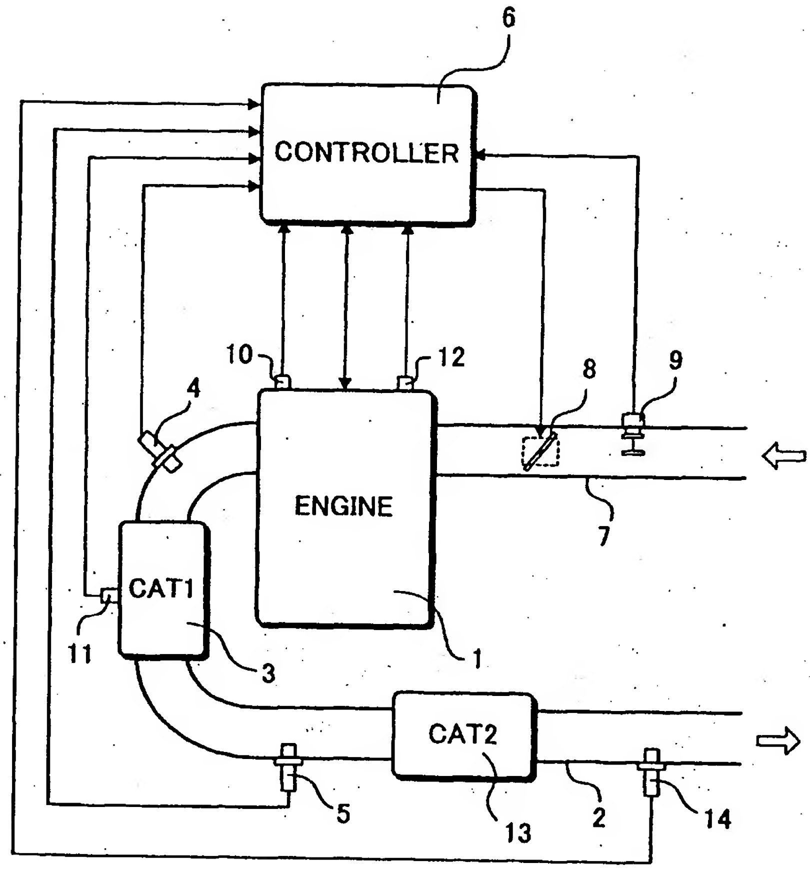

FIG. 13

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(54) **Engine exhaust purification device**

(57) A controller computes an oxygen storage amount of a catalyst based on the characteristics of an exhaust flowing into the catalyst, and controls the air-fuel ratio of an engine so that the oxygen storage amount of the catalyst is a target value. When it is determined that the engine starts from the warmed-up state when the engine starts, the air-fuel ratio of the engine is controlled to rich until the exhaust flowing out of the catalyst becomes rich. In this way, all the oxygen stored by the catalyst is first released, the NOx purification performance of the catalyst is maintained, and the NOx release amount immediately after engine startup is suppressed.

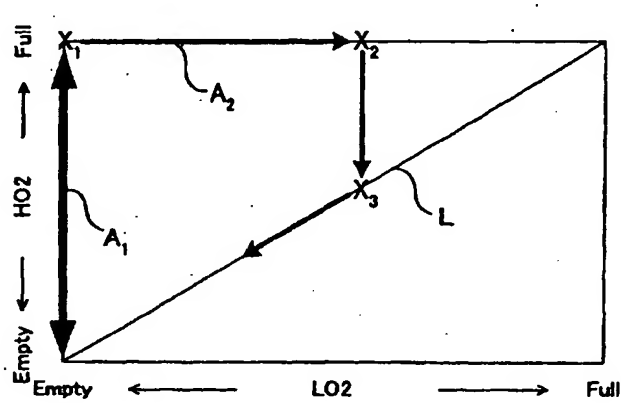

FIG.2

EP 1 128 042 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 10 4039

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 5 845 486 A (MATSUMOTO TOSHIKI ET AL) 8 December 1998 (1998-12-08) * column 1, line 51 - column 2, line 12 * * column 8, line 48 - column 9, line 34 * ---	1	F02D41/02 F01N11/00 F02D41/06
A	US 5 606 855 A (TOMISAWA NAOKI) 4 March 1997 (1997-03-04) * column 5, line 58 - column 6, line 31 * * column 6, line 55 - column 7, line 2 * ---	1	
A	US 5 901 552 A (RODUNER CHRISTIAN ET AL) 11 May 1999 (1999-05-11) * column 1, line 56 - line 33 * * column 2, line 57 - column 3, line 20 * -----	1	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

F02D
F01N
F02B
F02N

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	3 September 2003	Pileri, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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O : non-written disclosure
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D : document cited in the application
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 01 10 4039

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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03-09-2003

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EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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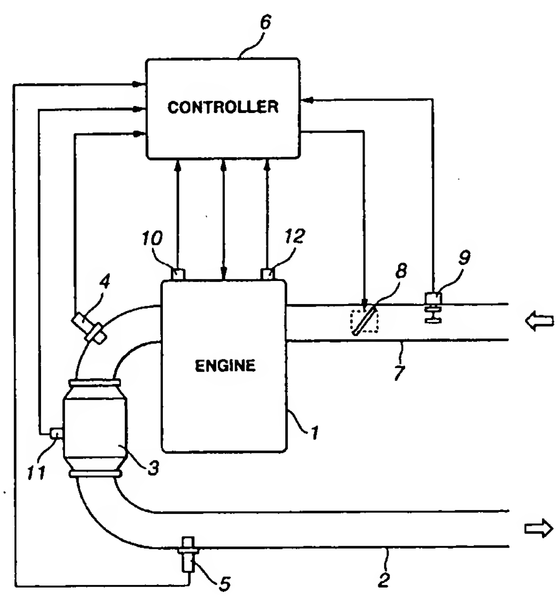
(54) Apparatus and method for engine exhaust purification

(57) An oxygen storage amount of a catalyst (3) is estimated by a controller (6) in accordance with a sensed air-fuel ratio of an inflowing exhaust gas mixture flowing into the catalyst (3), and a sensed intake air amount of the engine (1), to control the air-fuel ratio of the engine. The estimated oxygen storage amount is corrected to reduce an error in computing the estimated oxygen storage amount when a downstream exhaust condition sensed by an exhaust sensor (5) disposed on the downstream of the catalyst (3) becomes equal to a predetermined threshold, which is modified in accordance with the intake air amount for better emission control performance.

FIG.1



EP 1 253 309 A1

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to technique of purifying exhaust gases of engine, and more specifically to apparatus and method of exhaust emission control for an engine equipped with a catalyst.

[0002] For maximizing the conversion efficiency of NOx, CO, and HC in three-way catalyst, the control of oxygen storage amount in the catalyst is effective. In this case, a catalyst system can control the atmosphere of the catalyst around stoichiometry to maximize the conversion efficiency, by controlling the oxygen storage amount at a constant level so that oxygen in exhaust gases is stored in the catalyst in the case of deviation of the exhaust gases flowing into the catalyst to the lean side, and that oxygen is released from the catalyst in the case of deviation to the rich side.

SUMMARY OF THE INVENTION

[0003] An object of the present invention is to further reduce exhaust emissions in technique of computing an oxygen storage amount in a catalyst.

[0004] According to one aspect of the present invention, an engine exhaust purifying apparatus comprises: an air flow sensor, a catalyst, an upstream exhaust sensor, a downstream exhaust sensor and a controller. The air flow sensor is arranged to sense an engine intake air amount. The catalyst is disposed in an engine exhaust passage. The upstream exhaust sensor is disposed in the engine exhaust passage on an upstream side of the catalyst, and arranged to sense an upstream exhaust condition representing an air-fuel ratio of an inflowing exhaust gas mixture flowing into the catalyst. The downstream exhaust sensor is disposed on a downstream side of the catalyst and arranged to sense a downstream exhaust condition representing an air-fuel ratio of an outflowing exhaust gas mixture flowing out of the catalyst. The controller is configured; to compute an estimated oxygen storage amount of the catalyst in accordance with the air-fuel ratio of the inflowing exhaust gas mixture and the engine intake air amount; to control an air-fuel ratio of the engine in accordance with the estimated oxygen storage amount so as to bring an actual oxygen storage amount of the catalyst to a desired value; to correct the estimated oxygen storage amount to reduce an error in computing the estimated oxygen storage amount when the downstream exhaust condition sensed by the downstream exhaust sensor becomes equal to a predetermined threshold; and to modify the threshold in accordance with the intake air amount.

[0005] According to another aspect of the present invention, an engine exhaust purifying process for an engine equipped with a catalyst disposed in an engine exhaust passage, comprises: computing an estimated oxygen storage amount of the catalyst in accordance with a sensed upstream exhaust condition representing an air-fuel ratio of an inflowing exhaust gas mixture flowing into the catalyst and a sensed engine intake air amount; controlling an air-fuel ratio of the engine in accordance with the estimated oxygen storage amount; correcting the estimated oxygen storage amount to reduce an error in computing the estimated oxygen storage amount when a downstream exhaust condition representing an air-fuel ratio of an outflowing exhaust gas mixture flowing out of the catalyst becomes equal to a predetermined threshold; and modifying the threshold in accordance with the sensed engine intake air amount.

[0006] According to still another aspect of the present invention, an engine exhaust purifying apparatus for an engine equipped with a catalyst, comprises: means for sensing an engine intake air amount; means for sensing an upstream exhaust condition representing an air-fuel ratio of an inflowing exhaust gas mixture flowing into the catalyst; means for sensing an downstream exhaust condition representing an air-fuel ratio of an outflowing exhaust gas mixture flowing out of the catalyst; and means for computing an estimated oxygen storage amount of the catalyst in accordance with the upstream exhaust condition of the inflowing exhaust gas mixture and the engine intake air amount; means for controlling an air fuel ratio of the engine in accordance with the oxygen storage amount; means for correcting the estimated oxygen storage amount to reduce an error in computing the estimated oxygen storage amount when the downstream exhaust condition sensed by said means for sensing the downstream exhaust condition becomes equal a predetermined threshold; and means for modifying the threshold in accordance with the intake air amount.

[0007] The other objects and features of this invention will become understood from the following description with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a schematic view showing an exhaust purifying apparatus according to one embodiment of the present invention.

[0009] FIG. 2 is a flowchart showing a routine performed by the exhaust purifying apparatus of FIG. 1, for computing an estimated oxygen storage amount representing an amount of oxygen stored in a catalyst.

[0010] FIG. 3 is a flowchart showing a subroutine, performed by the exhaust purifying apparatus of FIG. 1, for computing an excess/deficiency oxygen amount of an inflowing exhaust gas mixture flowing into the catalyst.

[0011] FIG. 4 is a flowchart showing a subroutine performed by the exhaust purifying apparatus of FIG. 1, for computing an oxygen release rate of high speed component.

[0012] FIG. 5 is a flowchart showing a subroutine performed by the exhaust purifying apparatus of FIG. 1, for computing a high speed component (HO2) of the oxy-

O interface. Controller 6 determines an estimated oxygen storage amount (high speed component HO2 and low speed component LO2) of catalyst 3 by computation in accordance with sensor signals from air flowmeter 9, front A/F sensor 4 and temperature sensor 10.

[0032] When high speed component HO2 of the computed oxygen storage quantity is greater than a predetermined value (which, in this example, is set equal to a half of the maximum capacity HO2MAX of the high speed component HO2), controller 6 shifts the air-fuel ratio of engine 1 to the rich side, and thereby decreases high speed component HO2. When, on the other hand, the high speed component HO2 is smaller than the predetermined value, then controller 6 shifts the air-fuel ratio of engine 1 to the lean side, and thereby increases the high speed component HO2. Thus, controller 6 functions to hold the high speed component HO2 of the oxygen storage quantity constant.

[0033] Moreover, controller 6 corrects a deviation, caused by computation errors, between the computed (or estimated) oxygen storage quantity and the actual oxygen storage quantity, by resetting the oxygen storage quantity, at a predetermined timing, in accordance with the downstream exhaust condition on the downstream side of catalyst 3. In this example, the downstream exhaust condition is the oxygen concentration on the downstream side of catalyst 3.

[0034] When rear O_2 sensor 5 signals a lean condition for a lean side judgment, controller 6 assumes that the high speed component HO2 at least is increased to its maximum, and resets the high speed component HO2 to the maximum capacity. When rear O_2 sensor 5 signals a rich condition for a rich side judgment, controller 6 resets each of the low speed component LO2 and high speed component HO2 to a minimum capacity since oxygen is no longer released from high speed component HO2 and even from low speed component LO2.

[0035] The system of this example varies slice levels (rich side threshold RDT and lean side threshold LDT) for rich judgment and lean judgment of rear O_2 sensor 5 in accordance with an engine operating condition of engine 1. In this example, the slice levels are shifted to the lean side as the intake air quantity Qa for engine 1 increases. The amount of exhaust emission passing through catalyst 3 without being purified, and hence the efficiency of purifying the exhaust emission are influenced by setting of the slice levels. Therefore, this system is configured to shift the slice levels to the lean side in accordance with the intake air quantity Qa so as to optimize the exhaust emission purifying efficiency.

[0036] Controller 6 serves as a central unit of a control system by performing various control operations. The following description is directed to computation of the oxygen storage amount, resetting of the oxygen storage amount and air/fuel ratio control based on the oxygen storage amount.

[0037] FIG. 2 shows a routine for computing or estimating the oxygen storage amount of catalyst 3. The routine is performed at regular intervals of a predetermined time length by controller 6.

[0038] Step S1 is a step for reading various engine operating parameters of engine 1. In this example, controller 6 reads sensor signals of coolant temperature sensor 10, crank angle sensor 12 and air flowmeter 9. In accordance with information obtained at step S1, controller 6 estimates the temperature TCAT of catalyst 3 at step S2. Step S3 determines whether catalyst 3 is activated or not, by comparing the estimated catalyst temperature TCAT with a catalyst activation temperature TACTo.

[0039] When estimated catalyst temperature TCAT is higher than activation temperature TCATo, then controller 6 proceeds from step S3 to step S4 to compute the oxygen storage quantity. When the catalyst temperature is still lower than or equal to activation temperature TCATo, then controller 6 terminates the routine, assuming that catalyst 3 is in the state performing no oxygen storage/release operation.

[0040] At step S4, controller 6 computes an oxygen excess/deficiency amount O2IN in an inflowing exhaust gas mixture flowing into catalyst 3, by a subroutine shown in FIG. 3. At next step S5, controller 6 computes an oxygen release rate A of the high speed component of the oxygen storage amount, by performing a subroutine shown in FIG. 4.

[0041] At step S6, controller 6 computes an overflow amount OVERFLOW representing a quantity of oxygen overflowing into the low speed component LO2 without being stored in the high speed component HO2, by performing a subroutine of FIG. 5, for computing the high speed component HO2 of the oxygen storage amount. Overflow amount OVERFLOW is determined in accordance with oxygen excess/deficiency amount O2IN and oxygen release rate A of high speed component HO2.

[0042] At step S7, controller 6 determines whether all the oxygen excess/release amount O2IN of the inflowing exhaust gas mixture flowing into catalyst 3 is stored as high speed component HO2, or not, by checking the overflow amount OVERFLOW. When oxygen excess/deficiency amount O2IN is stored entirely in the high speed component, and hence overflow amount is equal to zero (OVERFLOW=0), then controller 6 terminates the routine of FIG. 2. When overflow amount OVERFLOW is not equal to zero, controller 6 proceeds from step S7 to step S8, and computes the low speed component LO2 in accordance with overflow amount OVERFLOW representing the quantity of overflow from high speed component HO2, by a routine shown in FIG. 6.

[0043] In the above-mentioned example, the catalyst temperature TCAT is estimated from the engine coolant temperature, engine load and engine speed. However, it is optional to employ a temperature sensor 11, disposed in catalyst 3 as shown in FIG. 1, for directly sensing the temperature of catalyst 3.

[0044] In the example shown in FIG. 2, step S3 is interposed to omit the computation of oxygen storage

gen storage amount.

[0013] FIG. 6 is a flowchart showing a subroutine performed by the exhaust purifying apparatus of FIG. 1, for computing a low speed component (LO2) of the oxygen storage amount.

[0014] FIG. 7 is a flowchart showing a routine performed by the exhaust purifying apparatus of FIG. 1, for discriminating a reset condition.

[0015] FIG. 8 is a graph showing a relationship between a rich side threshold used in the routine of FIG. 7, and an NOx outflow rate.

[0016] FIG. 9 is a flowchart showing a routine performed by the exhaust purifying apparatus of FIG. 1, for setting the rich side threshold.

[0017] FIG. 10 is a graph showing a table used to determine the rich side threshold in accordance with an engine intake air amount.

[0018] FIG. 11 is a flowchart showing a routine performed by the exhaust purifying apparatus of FIG. 1, for resetting the estimated oxygen storage amount.

[0019] FIG. 12 is a flowchart showing a routine performed by the exhaust purifying apparatus of FIG. 1, for computing a target air-fuel ratio in accordance with the estimated oxygen storage amount.

[0020] FIG. 13 is a time chart showing effects of the control for controlling the oxygen storage amount constant.

[0021] FIG. 14 is a graph showing an oxygen storage/release characteristic of the catalyst used in this embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[0022] FIG. 1 shows an exhaust gas purifying apparatus (or exhaust purification arrangement) according to one embodiment of the present invention. An engine 1 of this example is a spark ignition engine. The exhaust gas purifying apparatus includes a catalyst (or catalytic converter) 3 disposed in an exhaust passage 2 for engine 1, an upstream exhaust sensor (front A/F sensor) 4 for sensing an exhaust condition on the upstream side of catalyst 3, a downstream exhaust sensor (rear O_2 sensor) 5 for sensing an exhaust condition on the downstream side of catalyst 3, and a controller 6.

[0023] In an intake passage 7 for engine 1, there are provided a throttle valve 8 and an air flowmeter (or air flow sensor) 9 for sensing an intake air quantity Qa regulated by throttle valve 8. Throttle valve 8 of this example is an electronically controlled throttle valve which can be controlled independently of driver's accelerator pedal operation. Engine 1 is provided with an engine coolant temperature sensor 10 and a crank angle sensor 12 for sensing an engine speed.

[0024] Catalyst 3 of this example is a three-way catalyst capable of purifying NOx, HC and CO at a maximum efficiency when the catalyst atmosphere is in a condition of the stoichiometric air/fuel ratio. In catalyst 3, catalyst carrier is coated with an oxygen storage material such as ceria (cerium oxide), and catalyst 3 can perform an oxygen storage function of storing (or absorbing) and releasing oxygen in accordance with the air-fuel ratio of inflowing exhaust gas mixture.

[0025] An oxygen storage amount in catalyst 3 is composed of a high speed component HO2 determined by the storage and release in noble metal (such as Pt, Rh, Pd) in catalyst 3, and a low speed component LO2 determined by the storage and release in the oxygen storage material of catalyst 3. Low speed component LO2 is characterized by a larger capacity of storing and releasing a larger amount of oxygen than the capacity of the high speed component. However, the storage/release rate or speed is slower in the case of low speed component LO2 than in the high speed component HO2.

[0026] Moreover, the high speed component HO2 and low speed component LO2 have the following characteristics.

[0027] As to oxygen storage operation, oxygen is stored preferentially in the high speed component HO2 until a maximum capacity HO2MAX of high speed component HO2 is reached. Thereafter, when the high speed component HO2 becomes unable to store more, the low speed component LO2 starts to store oxygen.

[0028] As to oxygen release operation, oxygen is released preferentially from high speed component HO2 when the ratio (LO2/HO2) of the low speed component LO2 to the high speed component HO2 is smaller than a predetermined value, i.e., when the high speed component HO2 is relatively large. When the ratio (LO2/HO2) of the low speed component LO2 to the high speed component HO2 is greater than or equal to the predetermined value, oxygen is released from both of the high speed component HO2 and low speed component LO2 so that the ratio (LO2/HO2) of the low speed component LO2 to the high speed component HO2 is held unchanged.

[0029] Upstream exhaust sensor of this example is a front A/F sensor 4 disposed on the upstream side of catalyst 3, and arranged to sense the air/fuel ratio of the exhaust gas mixture flowing into catalyst 3. Downstream exhaust sensor of this example is a rear O_2 sensor 5 disposed on the downstream side of catalyst 3, and arranged to sense an oxygen concentration on the downstream side of catalyst 3 with reference to the stoichiometric air/fuel ratio in a manner of sensing inversion. Though the oxygen sensor is advantageous in cost, it is optional to employ, as rear exhaust sensor, a rear A/F sensor capable of linearly sensing the air/fuel ratio on the downstream side of catalyst 3.

[0030] Coolant temperature sensor 10 is arranged to sensor the temperature of a cooling water for engine 1. The temperature sensed by coolant temperature sensor 10 is used for determining an operating condition of engine 1, and for estimating the temperature of catalyst 3.

[0031] Controller 6 of this example is a computer unit including at least a microprocessor, RAM, ROM and I/

quantity when catalyst temperature TCAT is lower than activation temperature TCATo. It is, however, optional to eliminate step S3, and to design the routine so as to reflect the influence from catalyst temperature, in the oxygen release rate A of high speed component HO2 and oxygen storage/release rate B of low speed component LO2.

[0045] FIG. 3 shows the subroutine (of step S4) for computing the oxygen excess/deficiency amount O2IN of the inflowing exhaust gas mixture flowing into catalyst 3. This subroutine is designed to compute the oxygen excess/deficiency amount in accordance with the air-fuel ratio on the upstream side of catalyst 3, and the intake air amount of engine 1.

[0046] Step S11 of FIG. 3 obtains input information by reading signals from front A/F sensor 4 and air flowmeter 9.

[0047] Step S12 computes an excess/deficiency oxygen concentration of the inflowing exhaust gas mixture flowing into catalyst 3, by conversion from the signal of front A/F sensor 4 to the air/fuel ratio by using a predetermined conversion table. The excess/deficiency oxygen concentration is a relative oxygen concentration with reference to the oxygen concentration at the stoichiometric air/fuel ratio. The excess/deficiency oxygen concentration is zero when the inflowing exhaust gas mixture is at the stoichiometric ratio, negative on the rich side, and positive on the lean side.

[0048] Step S13 converts the output of air flowmeter 9 into intake air amount by using a predetermined conversion table. Step S14 computes excess/deficiency oxygen amount O2IN of the inflowing exhaust gas mixture flowing into catalyst 3, by multiplying the intake air amount determined by step S13, by the excess/deficiency oxygen concentration determined by step S12. Since the excess/deficiency oxygen concentration is zero, negative and positive in accordance with the air/fuel ratio, as mentioned before, the excess/deficiency oxygen amount O2IN is zero when the inflowing exhaust gas mixture is at the stoichiometry, negative when the inflowing exhaust gas mixture is rich, and positive when the inflowing exhaust gas mixture is lean.

[0049] FIG. 4 shows the subroutine (of step S5) for computing the oxygen release rate A of high speed component HO2. The oxygen release rate of high speed component HO2 receives influence from the low speed component LO2. Therefore, this subroutine is arranged to compute the high speed oxygen release rate A in accordance with low speed component LO2.

[0050] First, step S21 determines whether a ratio LO2/HO2 of low speed component LO2 to high speed component HO2 is greater than or equal to a predetermined value AR. (In one example, AR is greater than one, and AR=10) When high speed component HO2 is relatively great as compared to low speed component LO2, and hence the ratio LO2/HO2 is smaller than AR, then controller 6 proceeds from step S21 to step S22, and sets the oxygen release rate A of high speed component equal to 1.0 (A=1.0) on the assumption that oxygen is released first from high speed component HO2.

[0051] When ratio LO2/HO2 is greater than or equal to AR, oxygen is released from high speed component HO2 and low speed component LO2 so that ratio LO2/HO2 remains unchanged. In this case, therefore, controller 6 proceeds from step S21 to step S23, and computes such a value of the oxygen release rate A of high speed component as to hold the ratio LO2/HO2 unchanged.

[0052] FIG. 5 shows the subroutine (of step S6) for computing high speed component HO2 of the oxygen storage amount. The subroutine of this example is arranged to compute high speed component HO2 in accordance with oxygen excess/deficiency quantity O2IN of the inflowing exhaust gas mixture flowing into catalyst 3, and oxygen release rate A of high speed component HO2.

[0053] Step S31 of FIG. 5 checks whether excess/deficiency oxygen amount O2IN is greater than zero, and thereby determines whether the high speed component HO2 is in a state for storing oxygen or in a state for releasing oxygen.

[0054] When the inflowing exhaust gas mixture flowing into catalyst 3 is lean, and hence excess/deficiency oxygen amount O2IN is greater than zero, then controller 6 proceeds to step S32 on the assumption that high speed component HO2 is in the state for storing oxygen. At step S32, controller 6 computes high speed component HO2 according to the following equation (1).

$$HO2 = HO2z + O2IN \qquad (1)$$

HO2z : a previous (most recent) value of high speed component HO2

[0055] When oxygen excess/deficiency amount O2IN is smaller than or equal to zero, and the high speed component is considered to be in the state for releasing oxygen, then controller 6 proceeds from step S31 to step S33, and computes high speed component HO2 according to the following equation (2).

$$HO2 = HO2z + O2IN \times A \qquad (2)$$

A : the oxygen releasing rate of high speed component HO2

[0056] Steps S34 and S35 are steps for examining whether the thus-computed high speed component HO2 determined at step S32 or S33 is greater than or equal to a maximum capacity HO2MAX of high speed component, and whether the component HO2 determined at step S32 or S33 is smaller than or equal to a minimum capacity HO2MIN (=0) of high speed component.

[0057] When high speed component HO2 is greater than or equal to maximum capacity HO2MAX, controller

6 proceeds from S34 to S36, and computes overflow amount (excess amount) OVERFLOW representing an amount of oxygen flowing over without being stored in high speed component HO2, according to the following equation (3).

$$\text{OVERFLOW} = \text{HO2} - \text{HO2MAX} \quad (3)$$

Moreover, high speed component HO2 [illegible] to max-imum capacity HO2MAX (H2O = HO2M[illegible] step S36.

[0058] When high speed component [illegible] is smaller than or equal to minimum capacity HO2[illegible] 6 proceeds from S35 to S37, and comp[illegible] amount (deficient amount) OVERFLOW [illegible] the amount of oxygen flowing over without [illegible] in high speed component HO2 according to the following equation (4).

$$\text{OVERFLOW} = \text{HO2} - \text{HO2MIN} \quad (4)$$

Moreover, high speed component HO2 is limited to minimum capacity HO2MIN (H2O = HO2MIN) at step S37. In this example, minimum capacity HO2MIN is set equal to zero. Therefore, the system computes, as a negative overflow amount, a deficient oxygen amount in the state in which high speed component HO2 is released entirely.

[0059] When high speed component HO2 is intermediate between maximum and minimum capacities HO2MAX and HO2MIN, then controller 6 proceeds from step S35 to step S38, and sets overflow amount OVERFLOW to zero since oxygen excess/deficiency amount of the inflowing exhaust gas mixture flowing into catalyst 3 is all stored in high speed component HO2.

[0060] In the case of high speed component HO2 being equal to or greater than maximum capacity HO2MAX, or equal to or smaller than minimum capacity HO2MIN, overflow amount OVERFLOW flowing over from high speed component HO2 is stored or released at low speed component LO2.

[0061] FIG. 6 shows a subroutine (of step S8) for computing low speed component LO2. This subroutine is designed to compute low speed component LO2 in accordance with overflow amount OVERFLOW overflowing high speed component HO2.

[0062] Step S41 computes low speed component LO2 according to the following equation (5).

$$\text{LO2} = \text{LO2z} + \text{OVERFLOW} \times \text{B} \quad (5)$$

LO2z : A previous (most recent) value of low speed component LO2

B : An oxygen storage/release rate of low speed component.

[0063] Oxygen storage/release rate B of low speed component LO2 is set to a positive value smaller than or equal to one. In reality, the characteristic of the rate differs between oxygen storage and oxygen release, and moreover, the real storage/release rate is affected by catalyst temperature TCAT, and low speed component LO2. Accordingly, it is optional to set the storage rate and the release rate separately as a variable. In this case, oxygen is excessive when overflow amount OVERFLOW is positive, and the oxygen storage rate B in this case is increased as catalyst temperature TCAT [illegible]ases, and increased as low speed component LO2 [illegible]ler. When overflow am[illegible]RFLOW [illegible]se [illegible] catalyst temperature TCAT increases and as low speed component LO2 increases.

[0064] Steps S42 and S43 check whether the thus-determined low speed component LO2 is over a maximum capacity LO2MAX or under a minimum capacity LO2MIN (=0) as in the computation of high speed component HO2.

[0065] When low speed component LO2 is greater than or equal to maximum capacity LO2MAX, controller 6 proceeds from S42 to S44, and computes oxygen excess/deficiency amount O2OUT overflowing low speed component LO2 according to the following equation (6).

$$\text{O2OUT} = \text{LO2} - \text{LO2MAX} \quad (6)$$

Moreover, low speed component LO2 is limited to maximum capacity LO2MAX (L2O = LO2MAX) at step S44. Oxygen excess/deficiency amount O2OUT flows out of catalyst 3 toward the downstream side.

[0066] When low speed component LO2 is smaller than or equal to minimum capacity LO2MIN, controller 6 proceeds from S43 to S45, and limits low speed component LO2 to minimum capacity LO2MIN (LO2 = LO2MIN).

[0067] FIG. 7 shows a routine for discriminating a reset condition to reset the oxygen storage amount. By resetting the oxygen storage amount, the system can cancel accumulated computation error, and thereby improve the accuracy in computation of the oxygen storage amount.

[0068] The routine of FIG. 7 checks the oxygen concentration on the downstream side of catalyst 3, determines whether the reset condition is satisfied to reset the oxygen storage amount (high speed component HO2 and low speed component LO2), and sets rich side flag Frich and a lean side flag Flean.

[0069] At step S51, controller 6 reads the output RO2 of rear O_2 sensor 5 disposed on the downstream side of catalyst 3 to sense the oxygen concentration on the downstream side of catalyst 3. Then, controller 6 compares the rear O_2 sensor output RO2 with a lean side threshold LDT for lean side judgment and a rich side threshold RDT for rich side judgment, at steps S52 and

S53.

[0070] When rear O_2 sensor output RO2 is lower than lean side threshold LDT, then controller 6 proceeds from step S52 to step S54, and sets the lean side flag Flean to one to indicate the fulfillment of a lean reset condition to reset the oxygen storage amount. When rear O_2 sensor output RO2 is higher than rich side threshold RDT, then controller 6 proceeds from step S53 to step S55, and sets the rich side flag Frich to one to indicate the fulfillment of a rich reset condition to reset the oxygen storage amount.

[0071] When rear O_2 sensor output RO2 is between lean side and rich side thresholds LDT and RDT, then controller 6 proceeds from step S53 to step S56, and resets the flags Flean and Frich to zero to indicate the unfulfillment of each of the lean reset condition and the rich reset condition.

[0072] The optimum thresholds to reduce the exhaust emissions vary in dependence on intake air amount Qa of engine 1. Therefore, each of the thresholds LDT and RDT is determined in accordance with the intake air amount Qa.

[0073] FIG. 8 shows a relationship, obtained experimentally, between the rich side threshold RDT and an NOx outflow rate (=a ratio of an amount of NOx flowing out of catalyst, to an amount of NOx flowing into catalyst). As shown in FIG. 8, a value of the rich side threshold RDT to achieve a target NOx outflow rate (3%, for example) is varied to the lean side as intake air amount Qa increases.

[0074] Adjustment of rich side threshold RDT to the lean side increases the likelihood of the rich reset to reset the computed oxygen storage amount to the minimum capacity. After the rich reset, engine 1 is operated at relatively lean air-fuel ratios so as to increase the oxygen storage amount.

[0075] It is possible to further decrease the NOx outflow rate by shifting rich side judgment threshold RDT, to the rich side of the value to achieve the target NOx outflow rate (as seen in FIG. 8). In this case, however, the outflow rates of HC and CO increase, and the exhaust emission tends to increase as a whole.

[0076] A relationship between lean side threshold LDT and the NOx release rate has a characteristic approximately identical to the characteristic shown in FIG. 8. A value of lean side threshold LDT to achieve the target NOx outflow rate is shifted to the lean side as intake air amount Qa increases.

[0077] Adjustment of lean side judgment threshold LDT to the lean side decreases the likelihood of the lean reset to reset the computed oxygen storage amount to the maximum capacity. After the lean reset, engine 1 is operated at relatively rich air-fuel ratios so as to decrease the oxygen storage amount. Thus, by decreasing the likelihood of the lean reset, the engine control system can indirectly increase the likelihood of the operation of engine in a relatively lean region.

[0078] FIG. 9 shows a routine for setting rich side threshold RDT.

[0079] At step S58, controller 6 reads intake air amount Qa of engine 1. Then, at step S59, controller 6 determines a value of rich side threshold RDT corresponding to the current value of intake air amount Qa by lookup from a table as shown in FIG. 10. Thus, rich side judgment threshold RDT is varied to the lean side as intake air amount Qa increases, and varied to the rich side as intake air amount Qa decreases. As shown in FIG. 10, the threshold decreases monotonically as Qa increases. In this example, the threshold decreases linearly as Qa increases.

[0080] A routine for setting lean side threshold LDT is similar to the routine of FIG. 9. Lean side threshold LDT is determined in dependence on intake air amount Qa by lookup from a table of a characteristic similar to the characteristic shown in FIG. 10. Thus, leans side threshold LDT is varied to the lean side as intake air amount Qa increases, and varied to the rich side as intake air amount Qa decreases.

[0081] In this example, rich side threshold RDT and lean side threshold LDT are determined by the two distinct routines. However, it is optional to first determine a center value between both thresholds, in accordance with intake air amount Qa by using a routine similar to the routine of FIG. 9, and then sets the rich side threshold RDT to a value resulting from addition of a predetermined fixed value d to the center value, and the lean side threshold value LDT to a value resulting from subtraction of the predetermined fixed value d from the center value. The relationship between the center value and intake air quantity Qa is similar to the characteristic shown in FIG. 10. The center value, and thresholds RDT and LDT are shifted to lean side as intake air quantity Qa increases. Because the predetermined value d is fixed, the interval between both thresholds RDT and LDT is always constant irrespective of variation in the center value.

[0082] FIG. 11 shows a routine for resetting the computed, estimated oxygen storage amount.

[0083] Steps S61 and S62 are steps for checking changes in lean side and rich side flags Flean and Frich, and determines whether the lean reset condition or rich reset condition is satisfied.

[0084] When fulfillment of the lean reset condition is confirmed by a change of lean side flag Flean from 0 to 1, controller 6 proceeds from step S61 to step S63, and resets high speed component HO2 of the oxygen storage amount to maximum capacity HO2MAX. In this case, controller 6 does not perform a resetting operation for low speed component LO2, and low speed component LO2 remains unchanged without being reset.

[0085] When fulfillment of the rich reset condition is confirmed by a change of rich side flag Frich from 0 to 1, controller 6 proceeds from step S62 to step S64, and resets high speed component HO2 and low speed component LO2 of the oxygen storage amount, respectively, to minimum capacities HO2MIN and LO2MIN.

[0086] These reset operations are based on the following idea. The oxygen storage rate of low speed component LO2 is slow. Therefore, after high speed component HO2 has reached the maximum capacity, xygen overflows to the downward side of the catalyst even if maximum capacity is not reached yet by low speed component LO2. Hence, it is possible to assume that at least the high speed component HO2 has reached the maximum capacity at the time point when the downstream side of the catalyst becomes lean.

[0087] At the time when the downstream side of the catalyst is rich, it is assumed that oxygen is not released even from low speed component LO2 releasing oxygen gradually. Each of high speed component HO2 and low speed component LO2 is considered to be in a state of minimum capacity, holding no or little oxygen.

[0088] FIG. 12 shows a routine for computing a target air/fuel ratio from the oxygen storage amount. Controller 6 of this example serves as a central unit of a control system performing an air/fuel ratio control (control to control the oxygen storage amount constant).

[0089] Controller 6 first reads high speed component HO2 of the current oxygen storage amount at step S71, and computes a deviation DHO2 of the current high speed component HO2 from a target high speed component value TGHO2 at step S72. (Deviation DHO2 is equal to oxygen excess/deficiency amount needed by catalyst 3.) The target high speed component value TGHO2 is set equal to a half of the maximum capacity HO2MAX of high speed component, in this example.

[0090] At step S73, controller 6 determines a target air-fuel ratio for engine 1 by converting the computed deviation DHO2 to a corresponding value of the air/fuel ratio.

[0091] Therefore, this routine of FIG. 12 sets the target air-fuel ratio to the lean side and functions to increase the oxygen storage amount (high speed component HO2) when high speed component HO2 of oxygen storage amount is smaller than the target value. When, on the other hand, the high speed component HO2 is greater than the target value, then the target air-fuel ratio for engine 1 is set to the rich side, and the routine functions to decrease the oxygen storage amount (high speed component HO2).

[0092] The thus-constructed exhaust purifying catalyst apparatus or system of this example is operated as follows:

[0093] When engine 1 is started, the exhaust purifying catalyst system starts the computation of oxygen storage amount of catalyst 3, and performs the air-fuel ratio control for engine 1 so as to hold the oxygen storage amount in catalyst 3 constant at a level to achieve a maximum conversion efficiency of catalyst 3.

[0094] The computation to estimate the oxygen storage amount in catalyst 3 is based on the air-fuel ratio of inflowing exhaust gas mixture flowing into catalyst 3, and the intake air amount to engine 1. In this example, the exhaust purifying catalyst system determines the oxygen storage amount by computing high speed component HO2 and low speed component LO2 separately in conformity with the real characteristic.

[0095] In this example, the computation is based on the assumption that, at the time of oxygen storage, high speed component HO2 stores oxygen first, and low speed component LO2 start storage when high speed component becomes unable to store any more. At the time of oxygen release, the assumption is that oxygen is released first from high speed component HO2 when the ratio (LO21/HO2) between low speed component LO2 and high speed component HO2 is smaller than or equal to the predetermined ratio AR, and oxygen is released from both of low speed component LO2 and high speed component HO2 so as to maintain the ratio AR when ratio LO2/HO2 becomes equal to ratio AR.

[0096] Then, the catalyst system controls the air-fuel ratio of engine 1 to the rich side and thereby decreases high speed component HO2 when high speed component HO2 is greater than the target value. When high speed component HO2 is smaller than the target value, the air-fuel ratio is controlled to the lean side to increase high speed component HO2.

[0097] Consequently, the catalyst system can hold the high speed component HO2 at the desired target value. Therefore, even if the air-fuel ratio of the inflowing exhaust gas mixture flowing into catalyst 3 deviates from the stoichiometry, the high speed component HO2 superior in response speed store or release oxygen immediately, and correct the air-fuel ratio of the catalyst atmosphere toward the stoichiometric ratio, so that the conversion efficiency of catalyst 3 is held at the maximum level.

[0098] Accumulation of errors during the computation increases the deviation between the estimated oxygen storage amount based on the computation and the actual oxygen storage amount. However, this catalyst system performs the reset operation to reset the estimated oxygen storage amount (high speed component HO2 and low speed component LO2) at the timing when the downstream side of catalyst 3 becomes rich or lean, and thereby corrects the deviation between the result of computation and the actual oxygen storage amount.

[0099] FIG. 13 shows variation of high speed component HO2 when the oxygen storage amount is controlled constant. In this example, the rear O_2 sensor output RO2 becomes smaller than lean side judgment threshold LDT and the lean reset condition is met at instant t1. Therefore, high speed component HO2 is reset to maximum capacity HO2MAX. In this case, no resetting operation is performed to low speed component LO2 since low speed component LO2 is not necessarily at maximum.

[0100] At each of instant t2 and t3, rear O_2 sensor output RO2 becomes greater than rich side threshold RDT and the rich reset condition is met. Therefore, high speed component HO2 is reset to minimum capacity HO2MIN. Minimum capacity HO2MIN is equal to zero

in this example. In this case, low speed component LO2 too is reset to the minimum capacity.

[0101] By resetting the oxygen storage amount at the timing when the exhaust gas mixture on the downstream side of catalyst 3 becomes rich or lean, the exhaust purifying catalyst system according to this embodiment can correct the deviation between the result of the computation to estimate the oxygen storage amount and the actual oxygen storage amount, and further improve the accuracy of the estimation of oxygen storage amount. As a result, this system can improve the accuracy of the air-fuel ratio control to hold constant the oxygen storage amount, and maintain the high conversion efficiency of catalyst.

[0102] The thresholds RDT and LDT (or the center value between them) is adjusted to the lean side as the intake air amount Qa for engine 1 becomes greater. Thus, this catalyst system increases the likelihood of the rich reset when intake air amount Qa is greater, and decreases the likelihood of the lean reset, so that the tendency for engine 1 to be operated in a relatively lean region is increased. This catalyst system can increases the possibility of engine operation on the lean side and thereby optimize the purification efficiency for the exhaust emission control.

[0103] FIG. 14 shows the oxygen storage/release characteristic of catalyst 3 employed in this example. The vertical axis shows the high speed component HO2 (an amount of oxygen stored in the noble metal) and the horizontal axis shows the low speed component LO2 (an amount of oxygen stored in the oxygen storage material).

[0104] In the normal running condition, low speed component LO2 is almost zero, and only high speed component HO2 varies according to the air-fuel ratio of exhaust flowing into the catalyst as shown by an arrow A1 in FIG. 14. High speed component HO2 is controlled, for example, to be half of its maximum capacity.

[0105] When, however, the fuel supply is cut off to the engine, or when engine 1 is restarted from the warm-up state (hot restart), the high speed component HO2 has reached its maximum capacity and oxygen is stored as the low speed component LO2 (arrow A2 in FIG. 14). The oxygen storage amount varies from a point X1 to a point X2.

[0106] When oxygen is released from the point X2, oxygen is preferentially released from high speed component HO2. When the ratio of low speed component LO2 to high speed component HO2 reaches a predetermined value (X3 in FIG. 14), oxygen is released from both the high speed component HO2 and low speed component LO2 so that the ratio of low speed component LO2 to high speed component HO2 is not varied. In other words, oxygen is released while moving on a straight line L shown in FIG. 14. On the line L, the low speed component LO2 is from 5 to 15, but preferably approximately 10, relative to the high speed component 1.

[0107] In the illustrated embodiment, at least one of step S1, step S11, S13, S58 and item 9 can correspond to means for sensing an engine intake air amount, and at least one of step S1, S11 and item 4 can correspond to means for sensing an upstream exhaust condition representing an air-fuel ratio of an inflowing exhaust gas mixture flowing into the catalyst. At least one of steps S51 and item 5 can correspond to means for sensing an downstream exhaust condition representing an air-fuel ratio of an outflowing exhaust gas mixture flowing out of the catalyst. At least one of steps S4~S8, S14, S22, S23, S36~S38, S44 and S45 can correspond to means for computing an estimated oxygen storage amount of the catalyst in accordance with the upstream exhaust condition of the inflowing exhaust gas mixture and the engine intake air amount. Step S73 can correspond to means for controlling an air fuel ratio of the engine in accordance with the oxygen storage amount. At least one of steps S63 and S64 can correspond to means for correcting the estimated oxygen storage amount to reduce an error in computing the estimated oxygen storage amount when the downstream exhaust condition becomes equal a predetermined threshold. At least step S59 can correspond to means for modifying the threshold in accordance with the intake air amount.

[0108] This application is based on a prior Japanese Patent Application No. 2001-131481. The entire contents of this Japanese Patent Application No. 2001-131481 with a filing date of April 27, 2001 are hereby incorporated by reference.

[0109] Although the invention has been described above by reference to certain embodiments of the invention, the invention is not limited to the embodiments described above. Modifications and variations of the embodiments described above will occur to those skilled in the art in light of the above teachings. The scope of the invention is defined with reference to the following claims.

Claims

1. An engine exhaust purifying apparatus comprising:

    an air flow sensor (9) arranged to sense an engine intake air amount;
    a catalyst (3) disposed in an engine exhaust passage;
    an upstream exhaust sensor (4) disposed in the engine exhaust passage on an upstream side of the catalyst, and arranged to sense an upstream exhaust condition representing an air-fuel ratio of an inflowing exhaust gas mixture flowing into the catalyst;
    a downstream exhaust sensor disposed on a downstream side of the catalyst and arranged to sense a downstream exhaust condition representing an air-fuel ratio of an outflowing ex-

haust gas mixture flowing out of the catalyst; and

a controller (6) configured;

to compute an estimated oxygen storage amount of the catalyst in accordance with the air-fuel ratio of the inflowing exhaust gas mixture and the engine intake air amount;

to control an air-fuel ratio of the engine in accordance with the estimated oxygen storage amount so as to bring an actual oxygen storage amount of the catalyst to a desired value;

to correct the estimated oxygen storage amount to reduce an error in computing the estimated oxygen storage amount when the downstream exhaust condition sensed by the downstream exhaust sensor becomes equal to a predetermined threshold; and

to modify the threshold in accordance with the intake air amount.

2. The engine exhaust purifying apparatus as claimed in Claim 1, wherein the downstream exhaust condition (RO2) is one of an oxygen concentration of the outflowing exhaust gas mixture and the air-fuel ratio of the outflowing exhaust gas mixture, and the controller (6) is configured to determine the threshold as a function of the intake air amount and to correct the estimated oxygen storage amount by resetting the estimated oxygen storage amount to a predetermined setting when the downstream exhaust condition sensed by the downstream exhaust sensor becomes equal to the predetermined threshold (LDT, RDT).

3. The engine exhaust purifying apparatus as claimed in Claim 1, wherein the controller is configured to modify the threshold to a lean side as the intake air amount increases.

4. The engine exhaust purifying apparatus as claimed in Claim 1, wherein the threshold comprises a rich side threshold (RDT) and a lean side threshold (LDT).

5. The engine exhaust purifying apparatus as claimed in Claim 4, wherein the controller is configured to modify the rich side threshold to the lean side as the intake air amount increases.

6. The engine exhaust purifying apparatus as claimed in Claim 4 or 5, wherein the controller is configured to modify the lean side threshold to the lean side as the intake air amount increases.

7. The engine exhaust purifying apparatus as claimed in Claim 4, wherein the controller is configured to modify the rich side threshold and the lean side threshold to a lean side by shifting a center value between the rich side threshold and the lean side threshold to the lean side as the intake air amount increases.

8. The engine exhaust purifying apparatus as claimed in one of Claims 1 ~ 7, wherein the controller is configured to compute the oxygen storage amount by computing a high speed component (HO2) having a first oxygen storage rate and a low speed component (LO2) having a second oxygen storage rate which is not equal to the first oxygen storage rate.

9. The engine exhaust purifying apparatus as claimed in Claim 8, wherein the controller is configured to compute the oxygen storage amount according to such a characteristic that the high speed component stores oxygen prior to the low speed component, and the low speed component starts to store oxygen after the high speed component becomes unable to store oxygen.

10. The engine exhaust purifying apparatus as claimed in Claim 8, wherein the controller is configured to compute the oxygen storage amount according to such a characteristic that the high speed component releases oxygen prior to the low speed component when a ratio (LO2/HO2) of the low speed component to the high speed component is smaller than a predetermined value.

11. The engine exhaust purifying apparatus as claimed in Claim 8, wherein the controller is configured to compute the oxygen storage amount according to such a characteristic that, when a ratio of the low speed component to the high speed component is greater than a predetermined value, oxygen is released from the high speed component and the low speed component so as to hold the ratio of the low speed component to the high speed component unchanged.

12. The engine exhaust purifying apparatus as claimed in Claim 8, wherein the controller is configured to control the air fuel ratio of the engine so as to bring the high speed component to a desired value.

13. The engine exhaust purifying apparatus as claimed Claim 8, wherein the controller is configured to reset each of the high speed component and the low speed component to a minimum capacity when the downstream exhaust condition sensed by the downstream exhaust sensor becomes equal to the rich threshold.

14. The engine exhaust purifying apparatus as claimed in Claim 8, wherein the controller is configured to reset the high speed component to a maximum capacity when the downstream exhaust condition

sensed by the downstream exhaust sensor becomes equal to the lean threshold.

15. An engine exhaust purifying process for an engine equipped with a catalyst disposed in an engine exhaust passage, the engine exhaust purifying process comprising:

    computing an estimated oxygen storage amount of the catalyst in accordance with a sensed upstream exhaust condition representing an air-fuel ratio of an inflowing exhaust gas mixture flowing into the catalyst and a sensed engine intake air amount;
    controlling an air-fuel ratio of the engine in accordance with the estimated oxygen storage amount;
    correcting the estimated oxygen storage amount to reduce an error in computing the estimated oxygen storage amount when a downstream exhaust condition representing an air-fuel ratio of an outflowing exhaust gas mixture flowing out of the catalyst becomes equal to a predetermined threshold; and
    modifying the threshold in accordance with the sensed engine intake air amount.

FIG.1

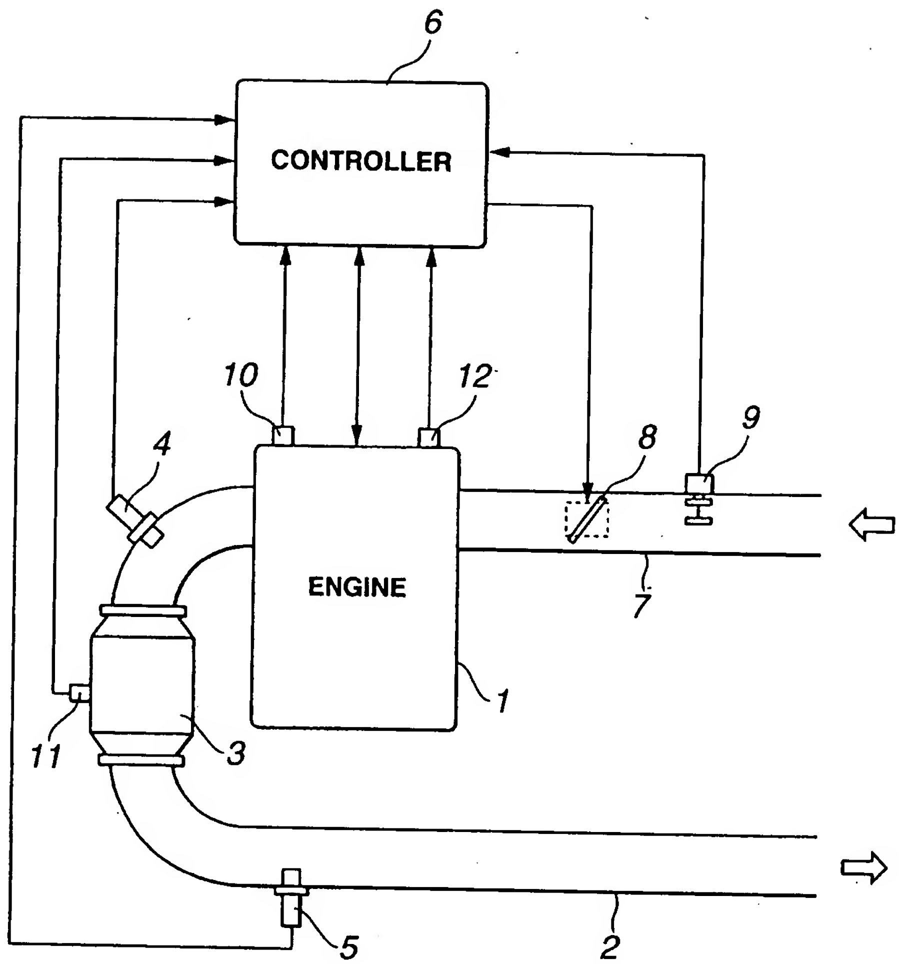


FIG.2

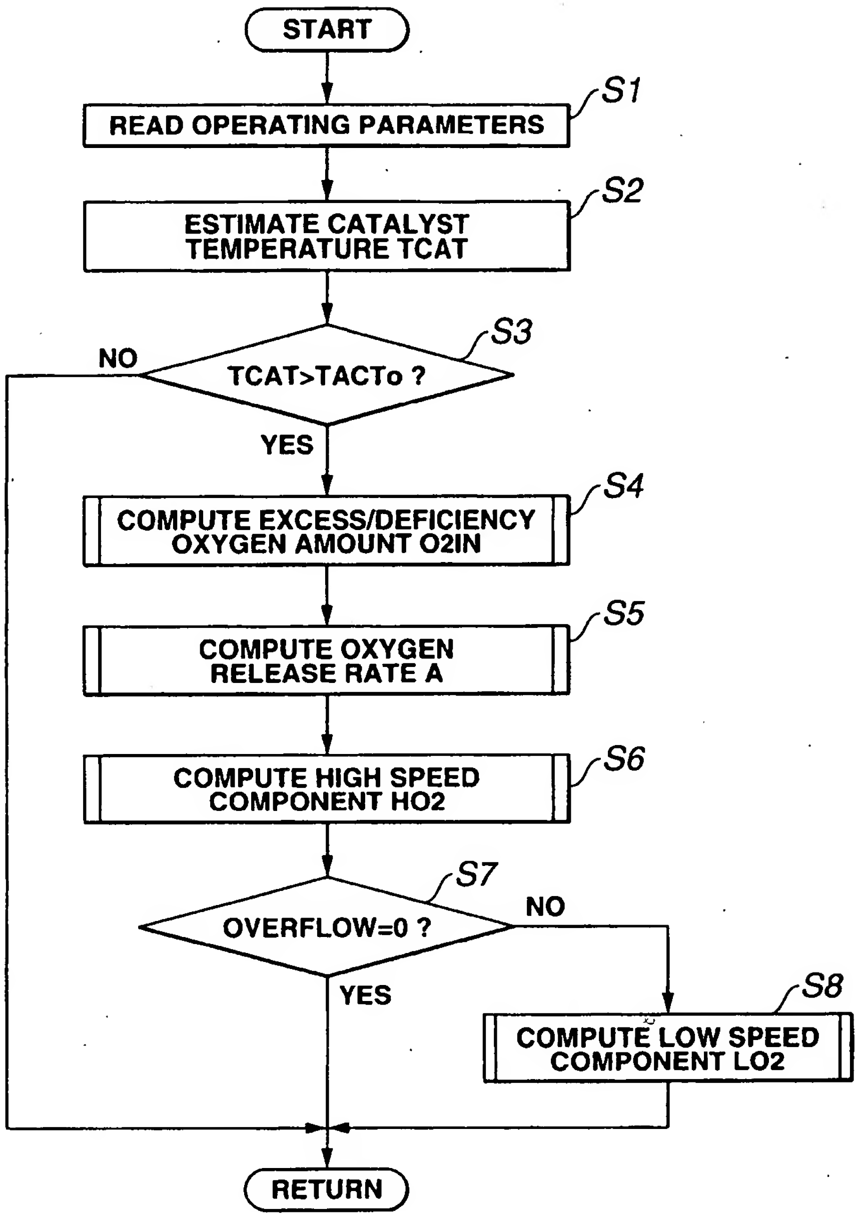

START
READ OPERATING PARAMETERS
S1
ESTIMATE CATALYST TEMPERATURE TCAT
S2
TCAT>TACTo ?
S3
NO
YES
COMPUTE EXCESS/DEFICIENCY OXYGEN AMOUNT O2IN
S4
COMPUTE OXYGEN RELEASE RATE A
S5
COMPUTE HIGH SPEED COMPONENT HO2
S6
OVERFLOW=0 ?
S7
NO
YES
COMPUTE LOW SPEED COMPONENT LO2
S8
RETURN

FIG.3

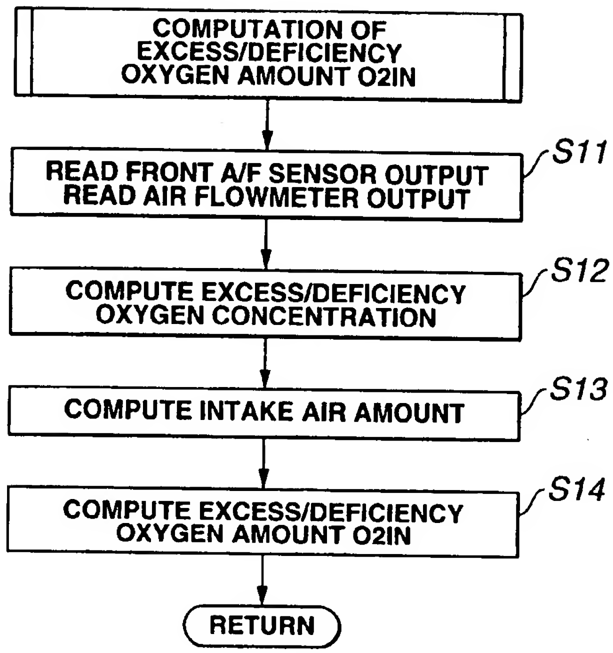

COMPUTATION OF EXCESS/DEFICIENCY OXYGEN AMOUNT O2IN
S11
READ FRONT A/F SENSOR OUTPUT
READ AIR FLOWMETER OUTPUT
S12
COMPUTE EXCESS/DEFICIENCY OXYGEN CONCENTRATION
S13
COMPUTE INTAKE AIR AMOUNT
S14
COMPUTE EXCESS/DEFICIENCY OXYGEN AMOUNT O2IN
RETURN

FIG.4

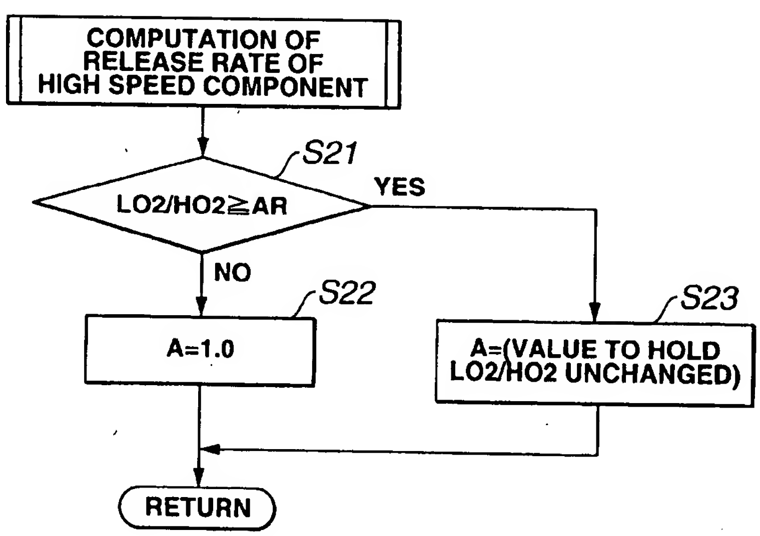
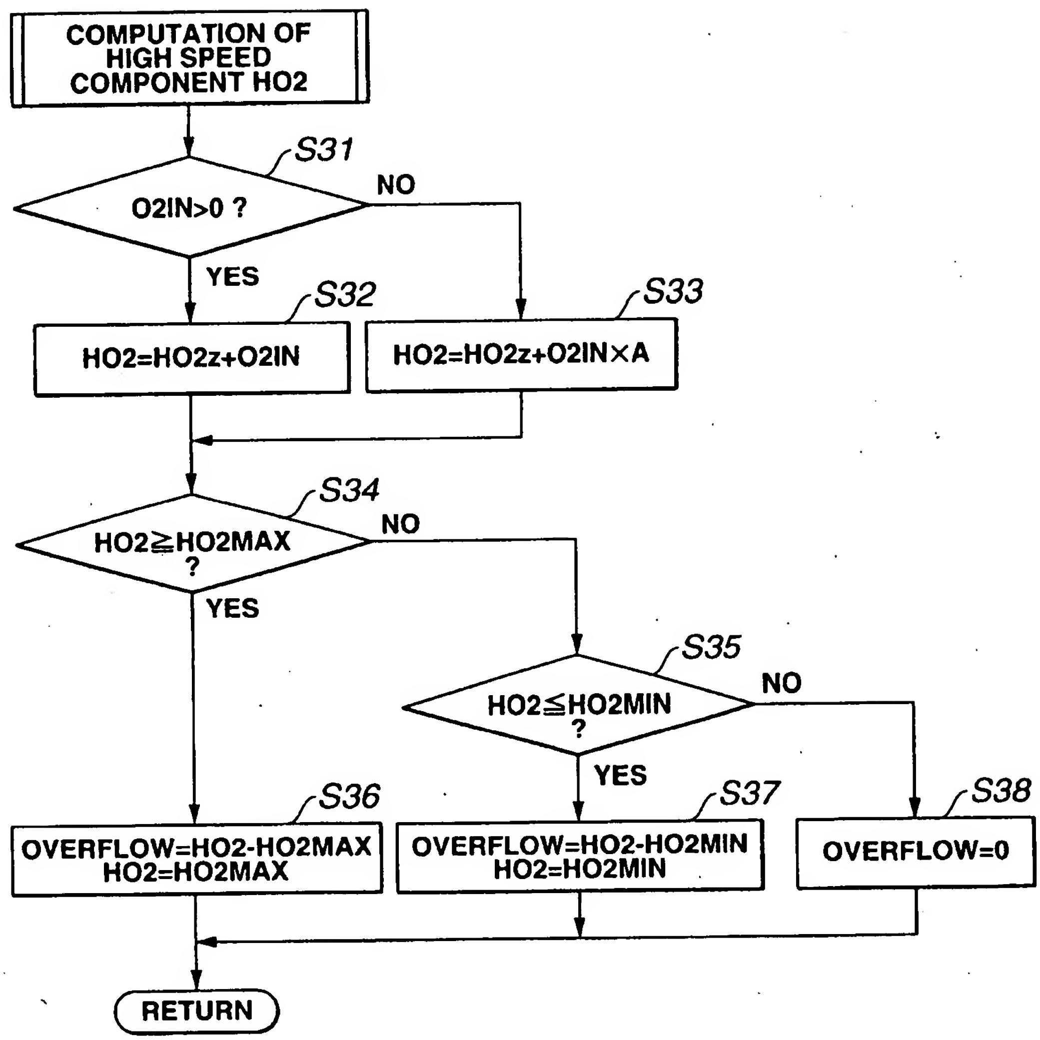

COMPUTATION OF RELEASE RATE OF HIGH SPEED COMPONENT
S21
LO2/HO2≧AR
YES
NO
S22
A=1.0
S23
A=(VALUE TO HOLD LO2/HO2 UNCHANGED)
RETURN

FIG.5



COMPUTATION OF HIGH SPEED COMPONENT HO2
S31
O2IN>0 ?
NO
YES
S32
HO2=HO2z+O2IN
S33
HO2=HO2z+O2IN×A
S34
HO2≧HO2MAX ?
NO
YES
S35
HO2≦HO2MIN ?
NO
YES
S36
OVERFLOW=HO2-HO2MAX
HO2=HO2MAX
S37
OVERFLOW=HO2-HO2MIN
HO2=HO2MIN
S38
OVERFLOW=0
RETURN

FIG.6

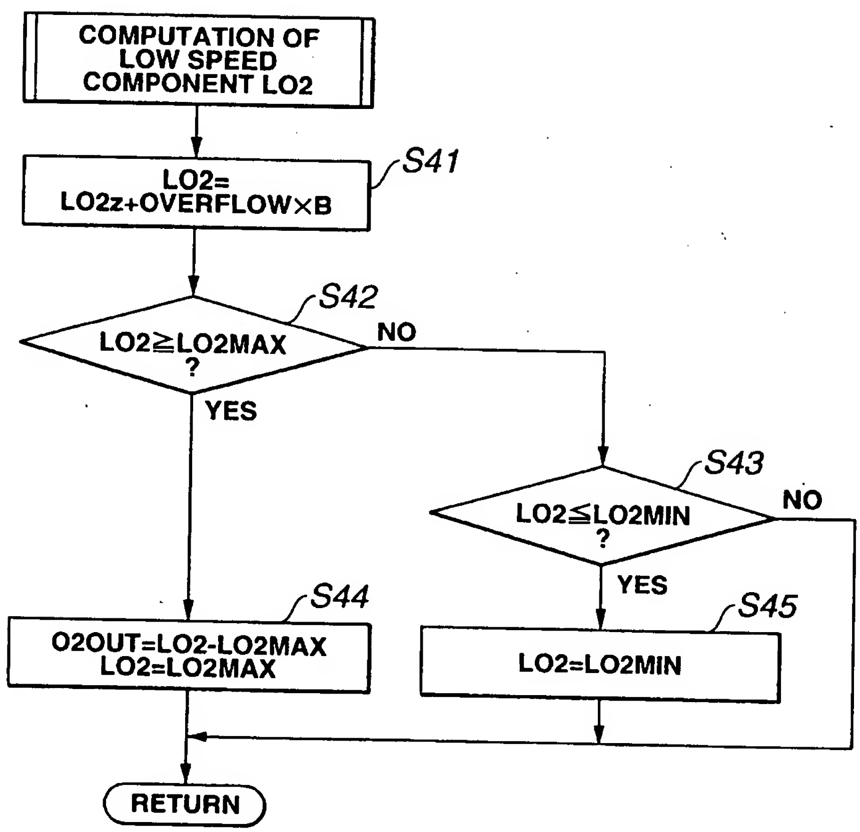

COMPUTATION OF LOW SPEED COMPONENT LO2
S41
LO2= LO2z+OVERFLOW×B
S42
LO2≧LO2MAX ?
NO
YES
S43
LO2≦LO2MIN ?
NO
YES
S44
O2OUT=LO2-LO2MAX
LO2=LO2MAX
S45
LO2=LO2MIN
RETURN

FIG.7

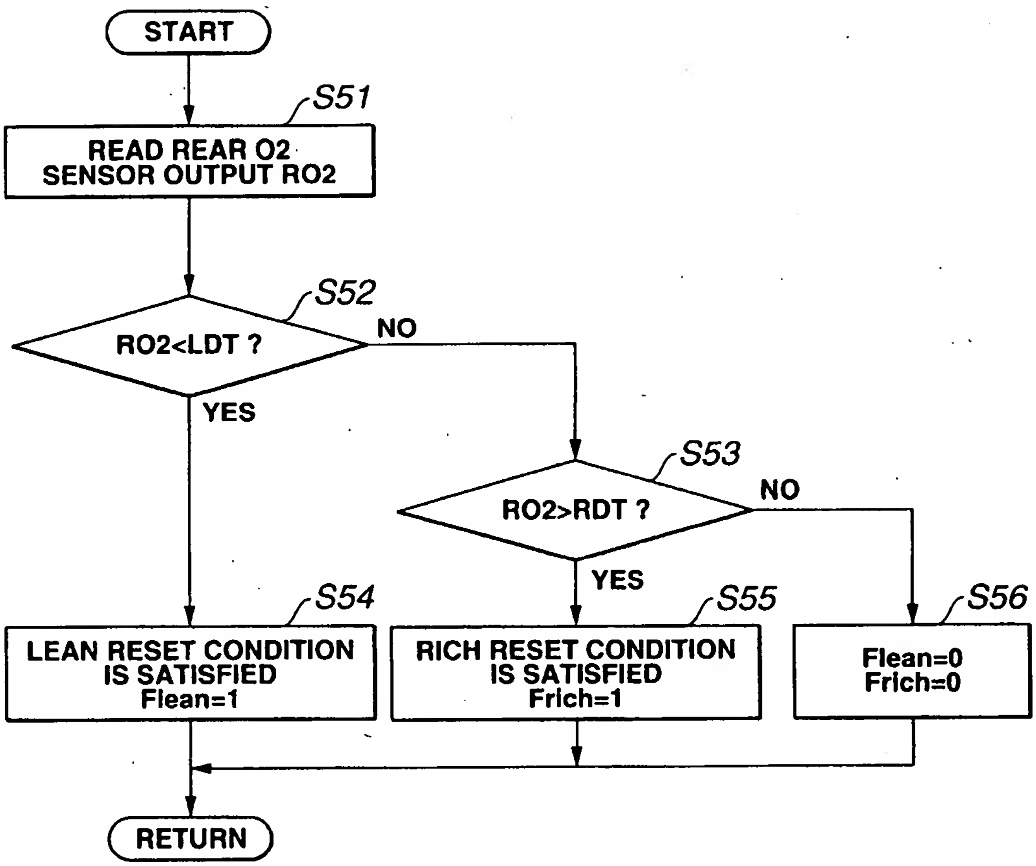

START
S51
READ REAR O2 SENSOR OUTPUT RO2
S52
RO2<LDT ?
NO
YES
S53
RO2>RDT ?
NO
YES
S54
LEAN RESET CONDITION IS SATISFIED Flean=1
S55
RICH RESET CONDITION IS SATISFIED Frich=1
S56
Flean=0 Frich=0
RETURN

FIG.8

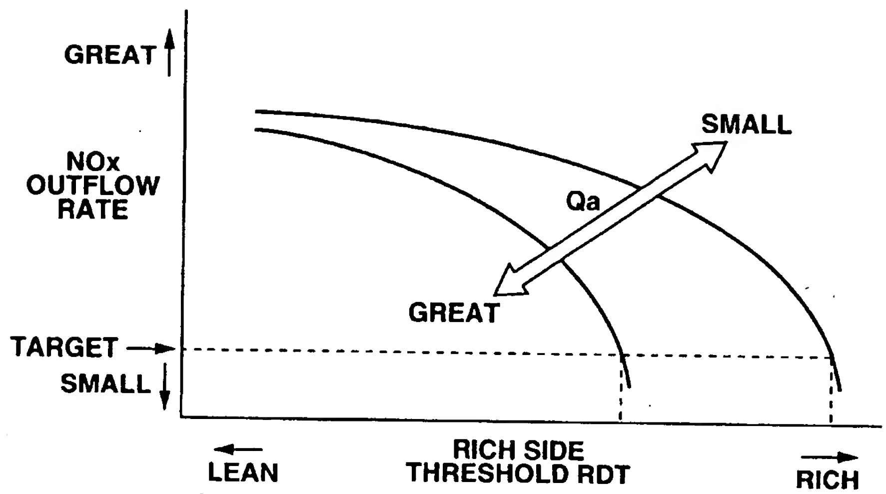

GREAT
NOx
OUTFLOW
RATE
TARGET
SMALL
SMALL
Qa
GREAT
LEAN
RICH SIDE
THRESHOLD RDT
RICH

FIG.9

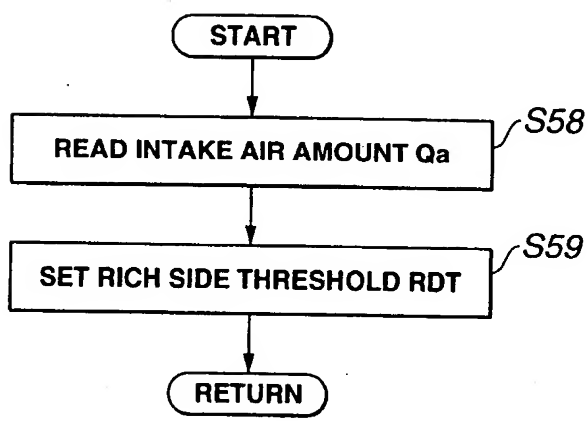

START
READ INTAKE AIR AMOUNT Qa
S58
SET RICH SIDE THRESHOLD RDT
S59
RETURN

FIG.10

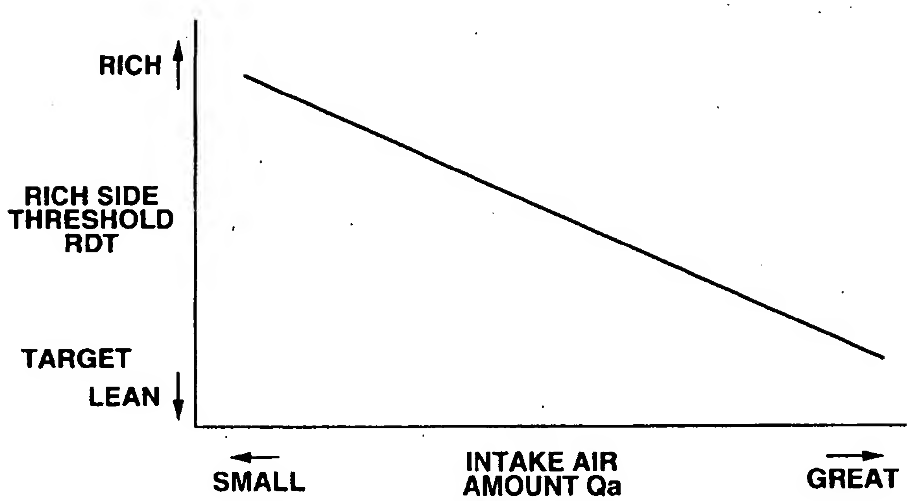

RICH
RICH SIDE THRESHOLD RDT
TARGET
LEAN
SMALL
INTAKE AIR AMOUNT Qa
GREAT

FIG.11

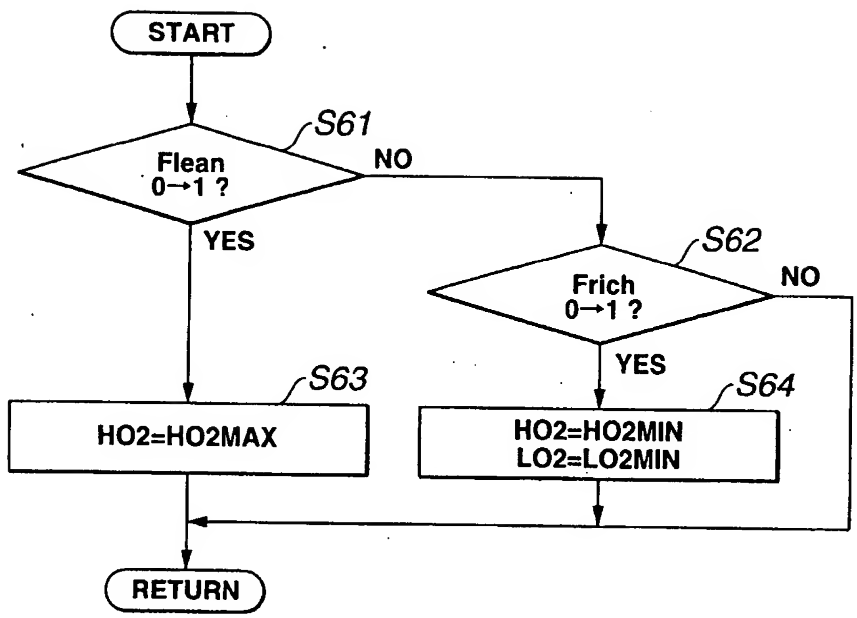

START
S61
Flean
0→1 ?
NO
YES
S62
Frich
0→1 ?
NO
YES
S63
HO2=HO2MAX
S64
HO2=HO2MIN
LO2=LO2MIN
RETURN

FIG.12

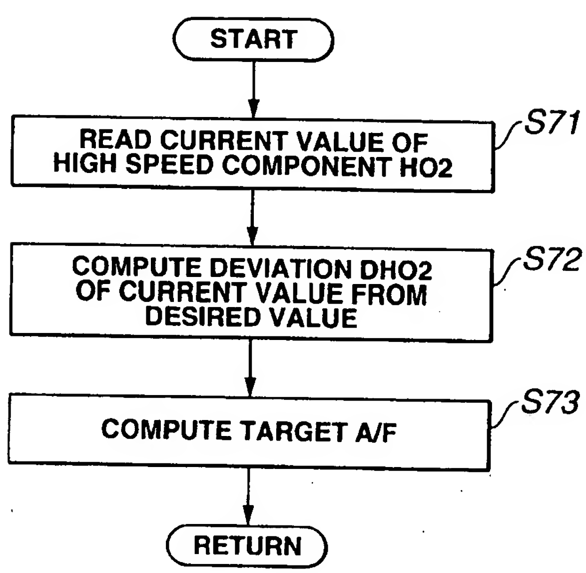

START
READ CURRENT VALUE OF
HIGH SPEED COMPONENT HO2
S71
COMPUTE DEVIATION DHO2
OF CURRENT VALUE FROM
DESIRED VALUE
S72
COMPUTE TARGET A/F
S73
RETURN

FIG.13

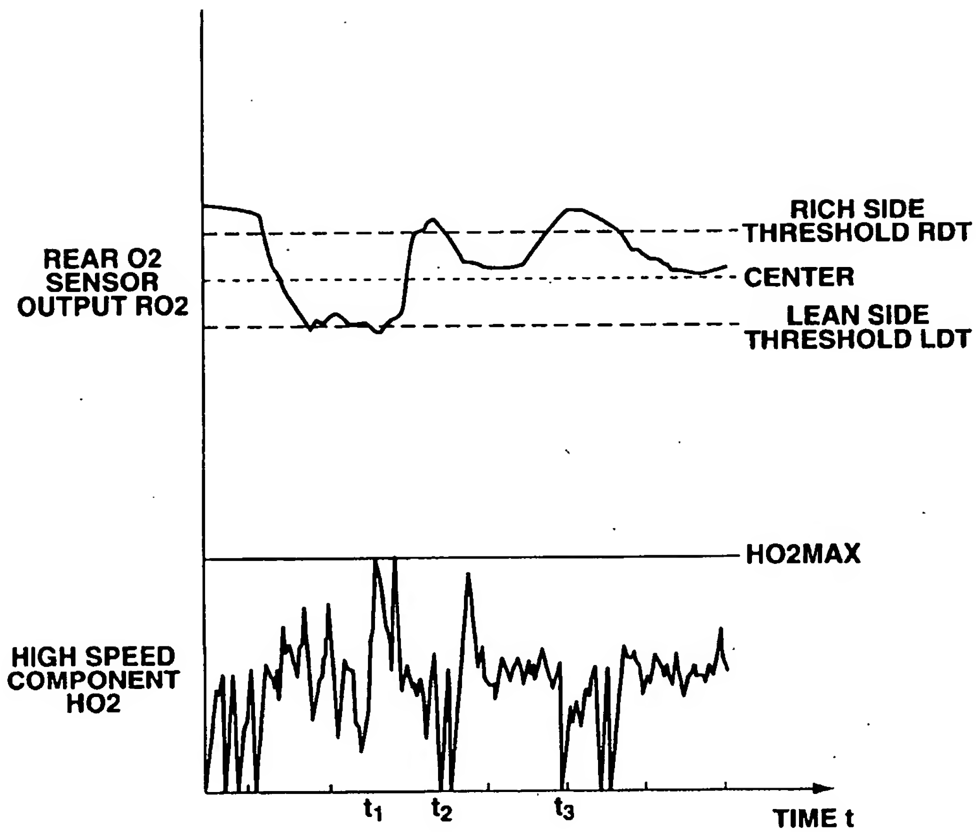
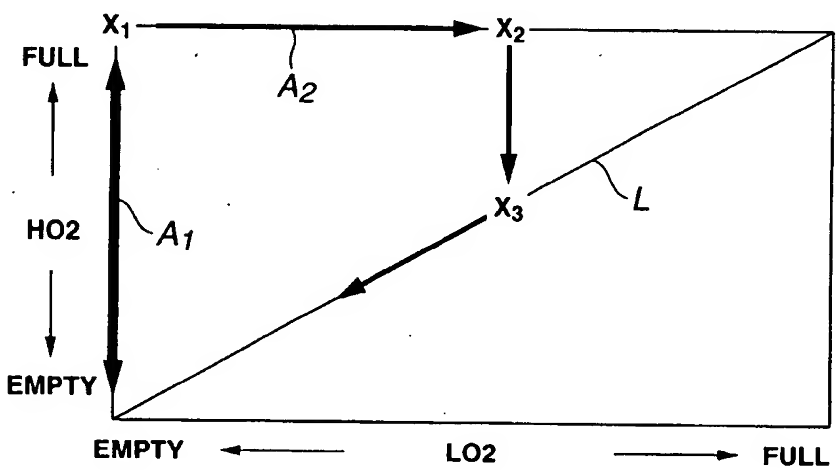

REAR O2 SENSOR OUTPUT RO2
RICH SIDE THRESHOLD RDT
CENTER
LEAN SIDE THRESHOLD LDT
HO2MAX
HIGH SPEED COMPONENT HO2
t_1
t_2
t_3
TIME t

FIG.14



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EUROPEAN SEARCH REPORT

Application Number
EP 02 00 6407

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X A	US 5 293 740 A (HEPPNER BERND ET AL) 15 March 1994 (1994-03-15) * column 2, line 26 - column 4, line 42 *	1,2,15 3-14	F02D41/02 F01N9/00
X	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 12, 31 October 1998 (1998-10-31) & JP 10 184426 A (TOYOTA MOTOR CORP), 14 July 1998 (1998-07-14) * abstract *	1,2,15	
Y A	US 5 609 023 A (KATOH AKIRA ET AL) 11 March 1997 (1997-03-11) * column 2, line 11 - column 4, line 25; figure 1 *	1,2,15 3-14	
Y A	US 6 185 933 B1 (NISHIZAWA KIMIYOSHI ET AL) 13 February 2001 (2001-02-13) * column 2, line 51 - column 6, line 16 *	1,2,15 3-14	
Y A	US 5 842 339 A (BUSH KEVIN J ET AL) 1 December 1998 (1998-12-01) * abstract * * column 6, line 60 - column 8, line 3 *	1,15 2-14	TECHNICAL FIELDS SEARCHED (Int.Cl.7) F02D F01N
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	12 July 2002	Wettemann, M

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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12-07-2002

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